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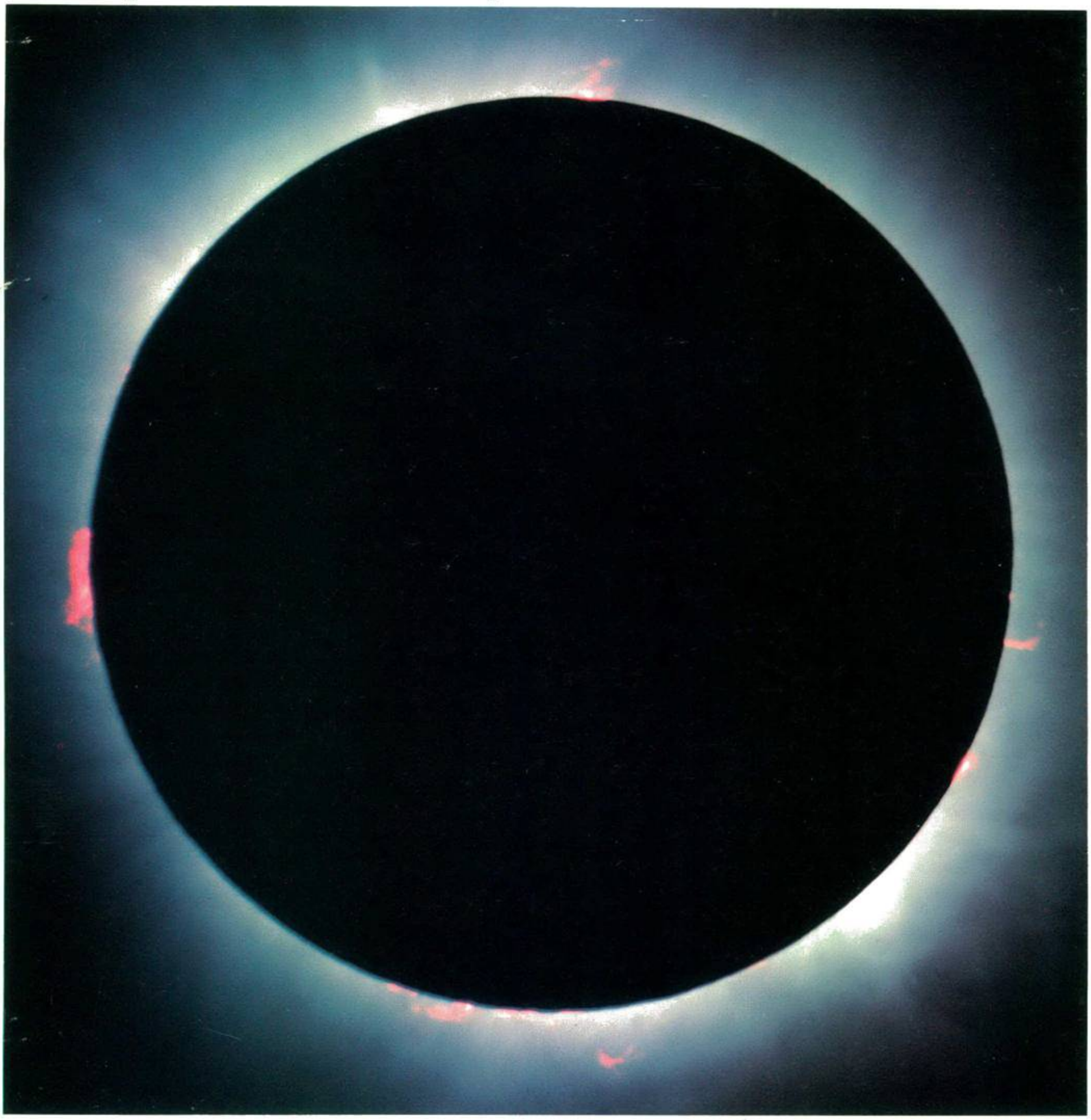

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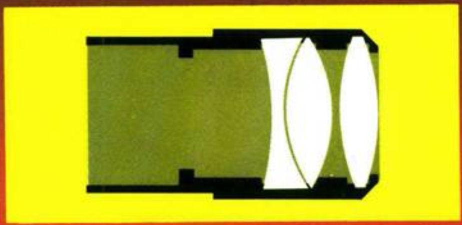

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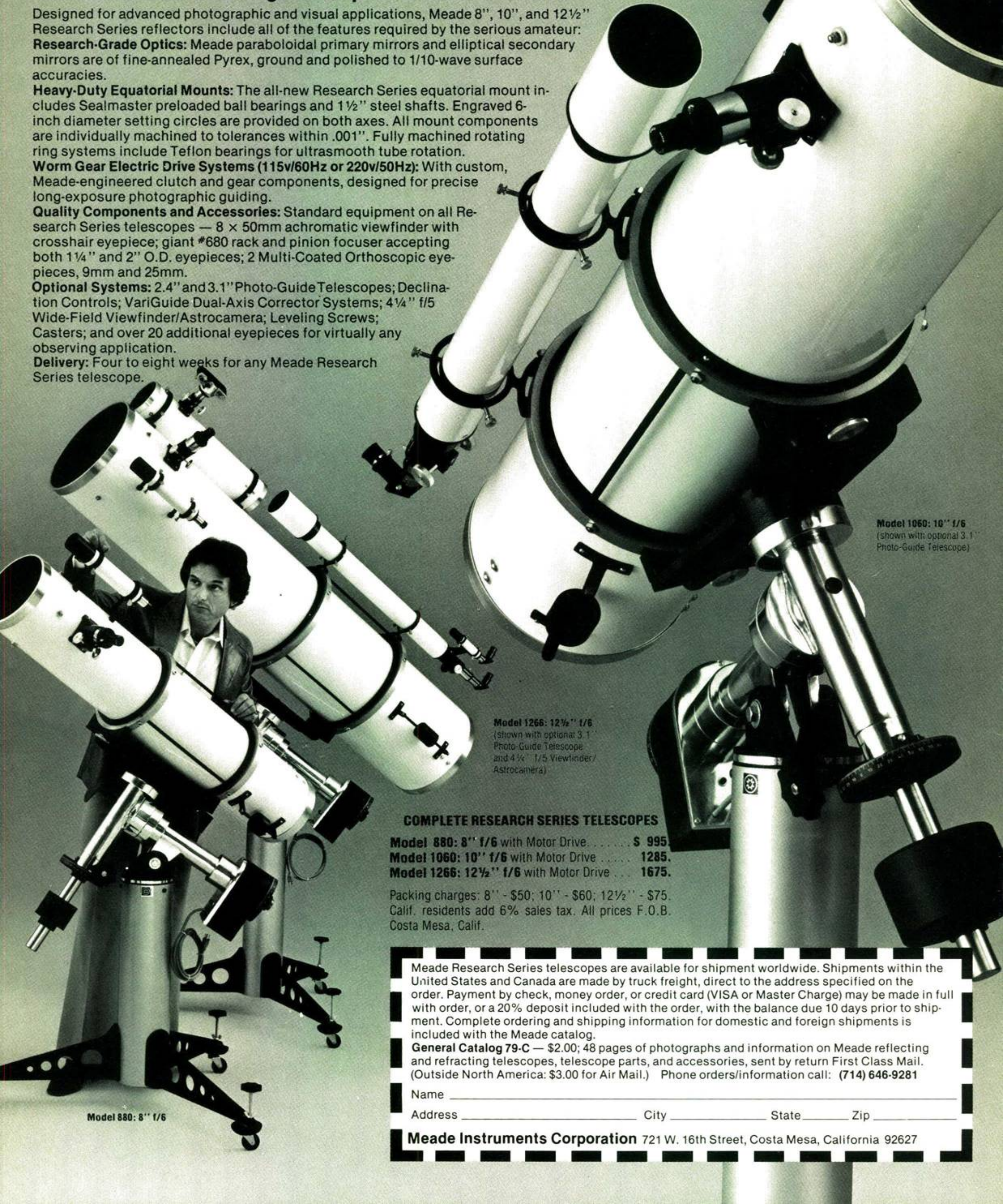

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Cover

While it might seem as if the news from Jupiter overpowered it in last month's issue, the total solar eclipse was a magnificent spectacle nonetheless. For those who went and saw it, the grand splendor will live long in memory. The cover photo, taken by Erik Wahlin near Williston, North Dakota, will remind those lucky viewers of the glorious sight that greeted them in the path of totality. This month, we've put together a pictorial summing-up of the sights. Our sole regret is that we could run only a tiny fraction of the many beautiful photos submitted.

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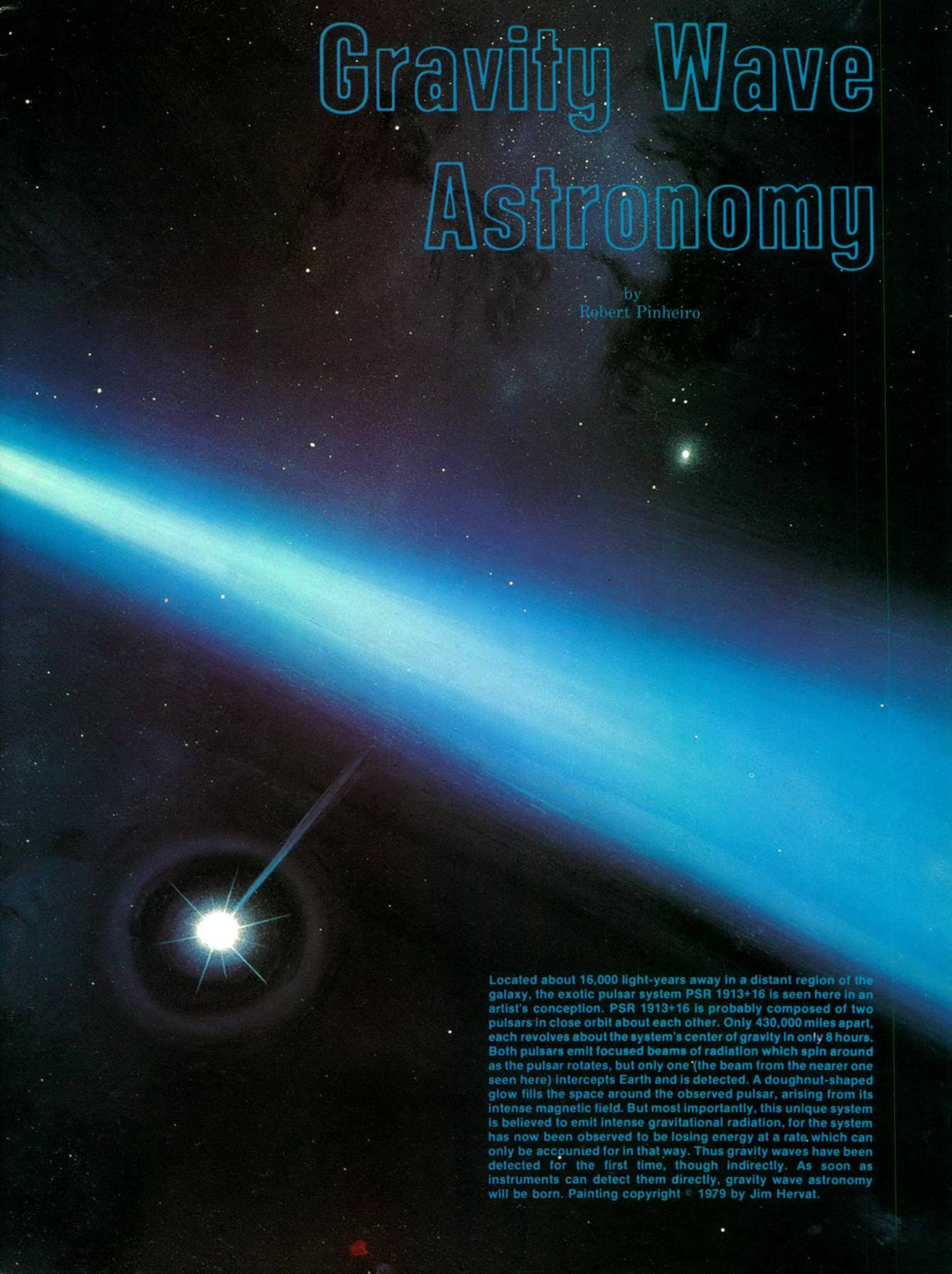
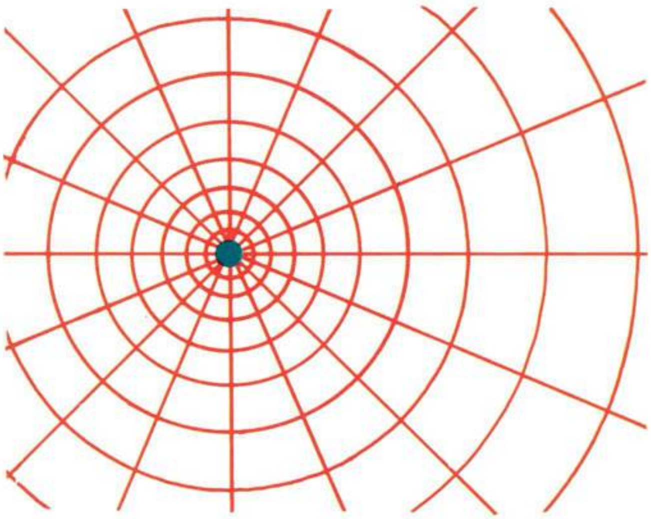
Gravity Wave Astronomy

by
Robert Pinheiro



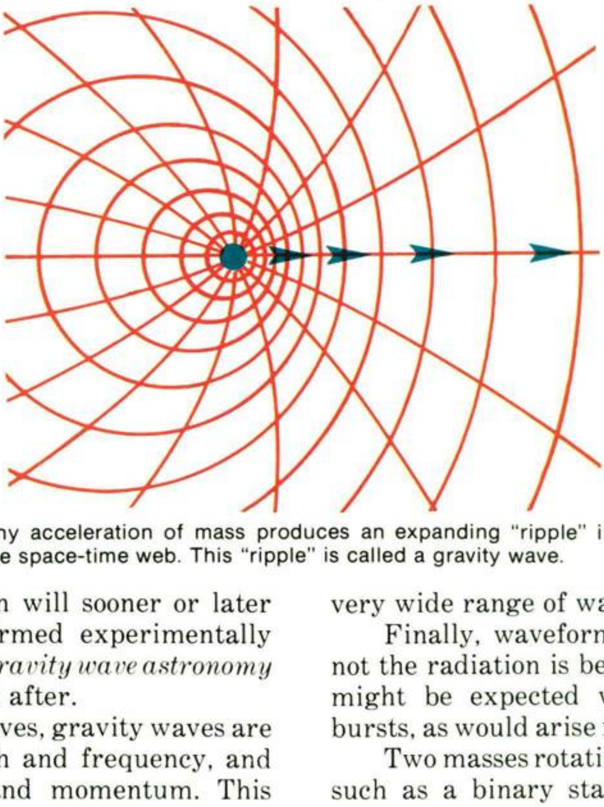
Located about 16,000 light-years away in a distant region of the galaxy, the exotic pulsar system PSR 1913+16 is seen here in an artist's conception. PSR 1913+16 is probably composed of two pulsars in close orbit about each other. Only 430,000 miles apart, each revolves about the system's center of gravity in only 8 hours. Both pulsars emit focused beams of radiation which spin around as the pulsar rotates, but only one (the beam from the nearer one seen here) intercepts Earth and is detected. A doughnut-shaped glow fills the space around the observed pulsar, arising from its intense magnetic field. But most importantly, this unique system is believed to emit intense gravitational radiation, for the system has now been observed to be losing energy at a rate which can only be accounted for in that way. Thus gravity waves have been detected for the first time, though indirectly. As soon as instruments can detect them directly, gravity wave astronomy will be born. Painting copyright © 1979 by Jim Hervat.

Everything we know about the universe at this point in history is due to our observations of the electromagnetic radiation emitted or reflected by astronomical objects, and all the recent revolutions in astronomy are due to the opening up of vast new ranges of the electromagnetic spectrum for observation. Our knowledge today is based not only on visible wavelengths, but on the infrared, ultraviolet, radio, and X-ray portions of the spectrum. But we may now be on the verge of an entirely different kind of revolution. Astronomers and physicists have begun to think about *another* kind of radiation, totally different from electromagnetic, which should be coming to us from deep space, and which could open an entirely new window to the universe — *gravitational radiation.*



Every mass distorts the surrounding web of space-time.

According to Albert Einstein's model of the physical universe, as well as every other model which holds up experimentally, a mass subjected to any kind of acceleration should emit *gravity waves,* just as an electric charge generates electromagnetic waves when accelerated. But even though theoretical predictions about the existence and properties of these waves had been around for some time, most scientists remained highly skeptical about their actual existence. Now, due largely to the recent announcement of indirect evidence for the existence of gravity waves (see **AstroNews** in this issue), gravitational radiation is being sought by investigators throughout the world, using a variety of sophisticated sensing devices. Even though past experimental results have been discouraging, most scientists now feel that the existence of this strange relativistic radiation will sooner or later (hopefully sooner) be confirmed experimentally here on Earth. The dawn of *gravity wave astronomy* will undoubtedly follow soon after.



Any acceleration of mass produces an expanding "ripple" in the space-time web. This "ripple" is called a gravity wave.

Like electromagnetic waves, gravity waves are characterized by wavelength and frequency, and carry with them energy and momentum. This energy manifests itself as stresses in the gravitational field exerted by the moving wave perpendicular to the wave's direction of motion. Since all matter "feels" the gravitational field, these stresses will interact with everything they encounter. But since this interaction is *very* weak, the waves can travel virtually unimpeded throughout the universe. Interstellar gas and dust, as well as other bodies getting in the way, will be transparent to them.

Three essential properties of gravity waves make them highly attractive to astronomers searching for yet another key to unlock more of the universe's secrets: *polarization, spectral energy density,* and *waveform.*

Polarization refers to a preferred orientation state of a wave's direction of vibration. Two independent states of polarization exist for gravity waves, each corresponding to a different orientation in space of their lines of force. A plane wave has two components, corresponding to each of these two states. Each component of polarization represents the momentary amplitude of the wave in each state. This acts as a unique signature which can provide clues about the wave's source, as well as the mathematical character of the wave.

The spectral energy density of a particular source refers to the amount of energy carried by gravity waves at different frequencies. Some sources, such as binary stars, would be highly "monochromatic," meaning that they would radiate at only a single frequency. Other sources, notably bodies undergoing cataclysmic explosions or collapses, would produce "broadband" radiation over a very wide range of wavelengths.

Finally, waveform has to do with whether or not the radiation is being emitted continuously, as might be expected with binaries, or rather in bursts, as would arise from an explosion or collapse.

Two masses rotating about their center of mass, such as a binary star system, are in fact being

Gravity according to Einstein...

Einstein's General Theory of Relativity, first published over sixty years ago, is one of the greatest intellectual achievements of all time. Although Newton's theory of gravity provided a measure of the force of gravity, it failed to account for the mechanism of gravity itself. Gravity seemed to be a quasi-magical force, operating instantaneously over a distance.

Einstein's theory is a classical *field theory* which describes the gravitational field in terms of the mathematical structure of space-time itself. A field theory provides equations by which the particular force at any point in space can be determined. According to Einstein, the force of gravity appears because the presence of mass in space-time distorts the very structure of that space-time in exactly calculable ways.

A field theory such as Einstein's is what is called a *tensor theory*, meaning that the gravitational field at any point in space needs ten numbers, called *potentials*, to describe it. Another kind of theory, called a *scalar theory*, needs only one number. The Brans-Dicke theory of gravitation, one of the General Theory's competitors, has both tensor and scalar properties.

The equations of Einstein's theory which describe the set of potentials are so complex that they have never been completely solved to provide a total description of a particular gravitational field. Instead, approximations are made which give solutions for simple cases. The so-called *weak-field solutions*, in which linear approximations of Einstein's equations are solved with the simplification of a relatively weak gravitational field, are well known. Unfortunately, the situations of most interest to modern astrophysicists are those in which the gravitational field is extraordinarily strong — such as with pulsars, black holes, and perhaps quasars.

The beauty and elegance of the complex mathematics as well as its internal consistency and completeness have stood as models of careful, insightful work. The great question for physicists in the decades since its publication, however, has been "Is it true?" That is, does Einstein's theory accurately represent reality?

Although it has successfully passed every test to which it has been subjected, the General Theory of Relativity is notoriously difficult to test, and it must be said that currently the evidence, though favorable, is not compelling. As a result, there are now a large number of competing theories of gravitation, so many, in fact, that some theorists have developed theories of gravitational theories in order to cope with the welter of ideas. The detection and examination of gravitational waves will help to decide among these competing theories.

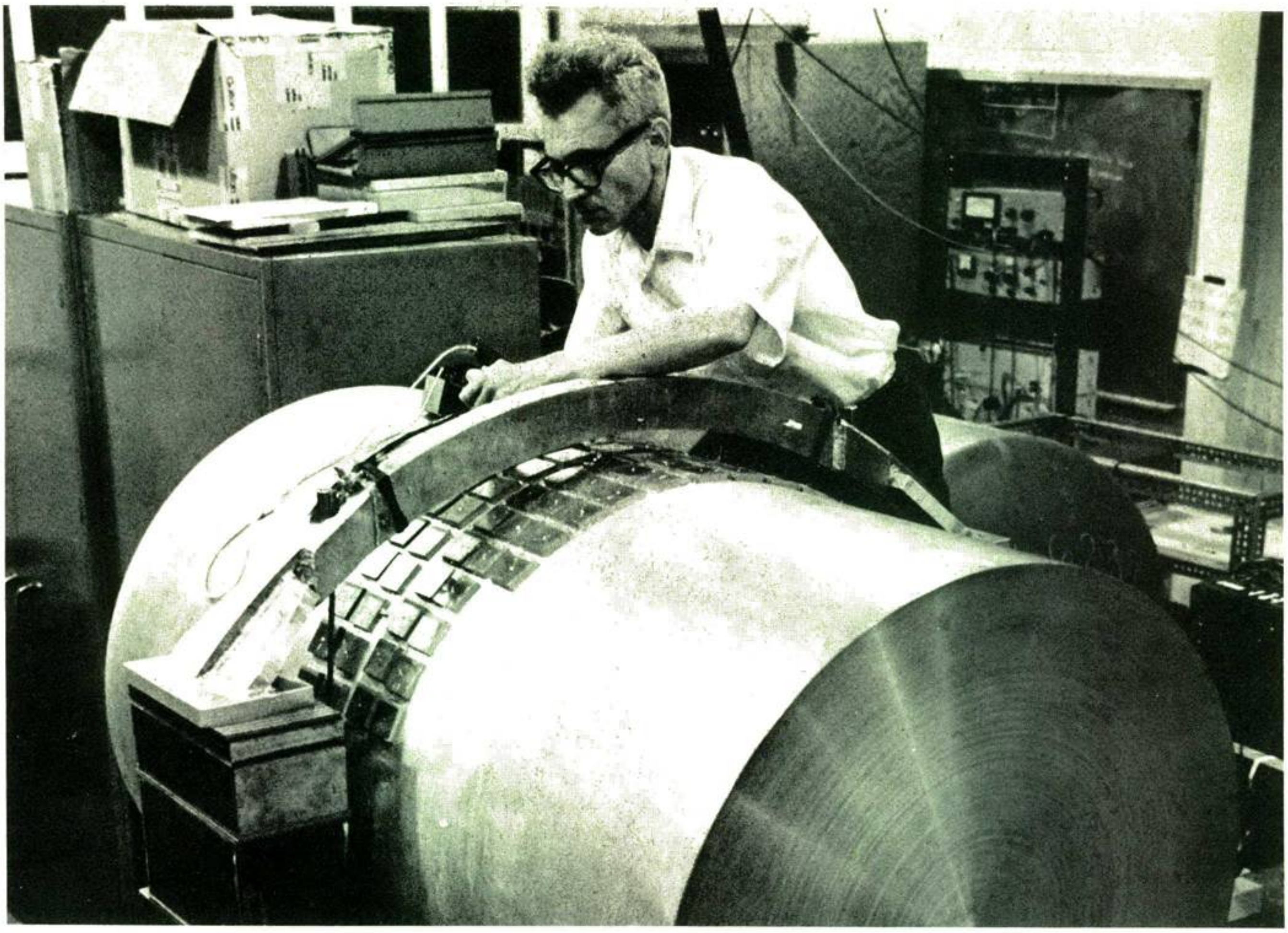
...and the other three forces

Modern physics knows of four fundamental forces. In addition to the force of gravity, these are the electromagnetic force, the strong nuclear force, and the weak nuclear force, each with its associated field. A long-desired goal in physics has been a unification of the four fields into one mathematical structure, which would be called, the *Unified Field Theory*. Such a unification has proved to be very elusive, however, and is probably still years in the future. A current theory unifying the weak force with the electromagnetic force is doing very well in experimental tests, and there is some hope for an incorporation of the strong nuclear force with the other two into a three-field unification.

But gravity remains a big question mark. The chief problem with Einstein's theory is that, for all its exotic strangeness, it is, in reality, a *classical* theory. That is to say, it is cast in a mathematical form similar to earlier, nineteenth century physical theories such as Maxwell's theory of the electromagnetic field. The great revolution in twentieth century physics has centered around the new mathematical constructs of *quantum* theory, with its non-deterministic equations of probability. In contrast to the revolutionary mathematics of quantum theories, which are used to describe the other three fields, Einstein's General Theory of Relativity, sophisticated and complex as it is, is mathematically "old-fashioned" — and, significantly, incompatible on a mathematical basis with the quantum theories which have dominated twentieth century physics.

As a result, physicists have not known quite what to do with Einstein's theory, since they have nothing better to offer in its place, but are unable to incorporate it with the rest of modern physics. So until recently it has just been hanging around on the outskirts of modern physics rather forlornly, like a little brother who hasn't been invited to the party.

Now, unprecedented efforts are being made to "quantize" General Relativity — to cast it into a mathematical form compatible with the theories of the other three fields. The task is incredibly difficult, but great strides are being made by such brilliant modern theorists as Stephen Hawking of Cambridge University. Once this has been accomplished, the now distant and ephemeral goal of a Unified Field Theory will be a little closer.



One of the gravity wave detectors used by Joseph Weber of the University of Maryland is seen above. It is an aluminum cylinder five feet long by three feet thick, mounted in an apparatus capable of measuring incredibly tiny variations in its length. Two of these "gravity wave telescopes" were used simultaneously to eliminate extraneous influences. Although Weber reported the detection of gravity waves, his results have not yet been reproduced by other scientists. Photograph courtesy of the University of Maryland.

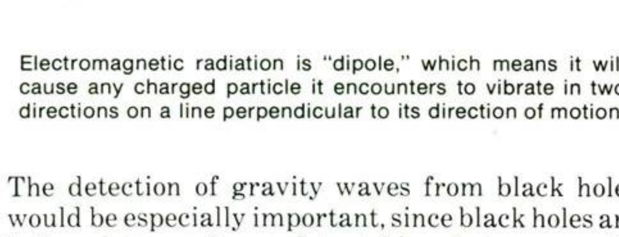
accelerated by gravity. Therefore the mathematical equations predict that a continuous stream of gravitational radiation at a frequency equal to twice the orbital period of the binary should result. If the binary orbited every 3½ days, then wave crests of gravitational radiation should pass us by every 7 days. The gravitational energy radiated in this way would depend upon the two masses involved, and would also be proportional to the sixth power of their angular velocity of rotation. Indeed, long ago (in 1916) Einstein made some calculations about the quantity of energy a binary system would lose via gravitational radiation. He concluded that the loss would be so small as to have no observable effect. But this was back in the days when the only known binaries had periods measured in days. Since then, binaries with periods measured in hours and even minutes have been discovered. For such rapidly rotating short-period binaries to exist, the two stars must necessarily be very close together, meaning that either or both of them would have to be highly compact white dwarfs, neutron stars, or even perhaps black holes. While the amount of energy radiated would still be small, it would be significantly greater than Einstein had predicted, and should be detectable.

An interesting and important consequence of all this is that, at some point, a flow of star material from the less massive to the more massive star would begin to take place. According to the theoretical models, the only mechanism by which this could realistically happen requires that energy and angular momentum be carried away from the system by gravity waves. It was observations of the slowing down of just such a system that now constitutes evidence for the existence of gravity waves (see AstroNews, ASTRONOMY, February 1979).

Perhaps the strongest gravitational radiation believed to occur is associated with supernovae and gravitational collapse. The imploding core of a star will send forth a large burst of gravity radiation, followed by a succession of small and large pulses. Such an event presents one of the most important and potentially useful applications of gravity astronomy, because it can provide a direct look into a star's collapsing core, something not possible in any other way (except maybe with neutrinos). Electromagnetic waves generated in the core would be absorbed by the star before ever reaching the surface. But by studying the gravity waves emitted, much may be learned about the mechanics of gravitational collapse.

A neutron star is the remnant of a star massive enough (having a mass of between 1.4 and 3 times the mass of our Sun) to have taken the route of gravitational collapse. Such a star arising out of a supernova will be imbued by the catastrophe with a large amount of vibrational energy, which will be rapidly dissipated by means of gravitational radiation. The birth of pulsars, or rotating neutron stars, is believed to occur in this manner. If the rotational motion of the newborn pulsar is not symmetrical, it will emit gravity waves. This lack of symmetry will be a result of deformations in the pulsar's shape, caused by its early, very rapid rotation. The monochromatic, continuous radiation would have a frequency equal to twice that of the pulsar's radio signals. The amount of energy radiated, for a pulsar of given mass, will again be proportional to the sixth power of its angular rotational velocity. Neutron stars may, from time to time, also experience "starquakes" which are thought to be responsible for the small jumps observed in the very precise period of the radio pulses. Gravity waves, although weak, would also be emitted by each quake. If they could be observed, they might be able to tell us much about what changes of shape pulsars undergo as they evolve.

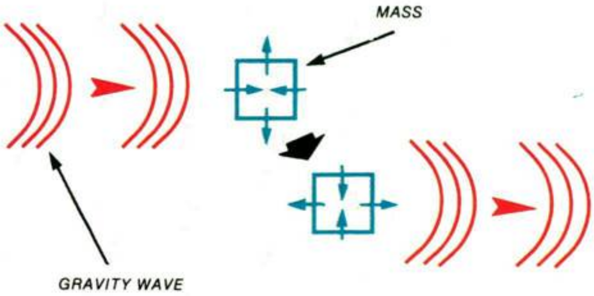
The famous but elusive black hole is yet another source for gravity waves. The gravitational radiation arising from the formation of a black hole would provide data on its mass and angular momentum. After its formation, a black hole may do further mischief by colliding with objects like stars and even other black holes, which would generate large bursts of gravitational radiation.



Electromagnetic radiation is "dipole," which means it will cause any charged particle it encounters to vibrate in two directions on a line perpendicular to its direction of motion.

The detection of gravity waves from black holes would be especially important, since black holes are believed to emit no detectable electromagnetic radiation. Gravity wave astronomy may be the only way they can be observed directly.

One theory about black holes proposes that extremely massive ones may be rotating in galactic centers, generating huge amounts of energy. Martin Rees, of Cambridge University, has suggested that such holes may be enclosed within a shell of matter drawn in from nearby surroundings, and are, in fact, what we observe as quasars. The quasar/black hole would be fueled by infalling matter from the shell, and perhaps also by swallowing stars whole. Various factors would determine how these things would appear from afar, but according to Rees, enough energy could be generated to match the energy thought to be emitted by quasars. The gravity waves generated by the infalling matter could play a large role in a better understanding of black hole and quasar phenomena.

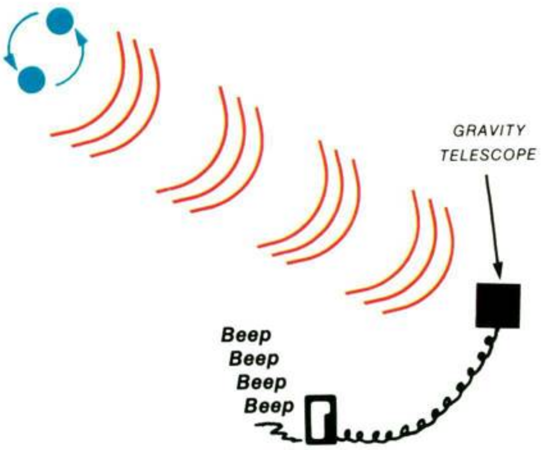


Gravitational radiation is "quadrupole," which means it will cause any mass it encounters to vibrate in four directions on a plane perpendicular to its direction of motion.

Another theory, proposed by the brilliant theoretical astrophysicist Stephen Hawking, implies that black holes actually radiate away mass over long periods of time. This would have a noticeable effect only in the case of microscopic black holes which some think may have been formed at the time of the Big Bang. Their mass loss would lead to an eventual explosion, releasing gargantuan amounts of energy — along with gravity waves. And, according to the theory, such explosions could be happening right now.

Before gravity wave astronomy becomes a real possibility, though, a thorny problem must be faced. Up till now, the basis for the understanding of gravity waves has involved the so-called "weak field solutions" to Einstein's equations. Black holes and many of the phenomena that would interest us, however, are associated with *strong* gravitational fields. The simple approximate solutions of Einstein's equations for relatively weak fields are on very shaky ground when extrapolated to fit these situations. More theoretical advances are needed for gravity wave astronomy to be truly productive.

Additional sources of gravity waves may exist. These include such things as galactic condensations and perhaps a gravitational analog to the microwave background radiation left over from the Big Bang. It has even been proposed that electromagnetic waves might be transformed into gravity waves if they passed through the gravitational field of a strongly charged black hole.



The acceleration of mass due to binary revolution would produce a continuous stream of gravity waves.

All these possibilities are, of course, highly conjectural, but they should keep the theorists busy calculating the different properties which would distinguish these many potential sources.

The future of gravity wave astronomy depends, of course, upon the technical capability of building and operating detectors sensitive enough to pick up gravitational radiation within the frequency ranges of interest. So far, this has been the nemesis of everyone involved. The most promising results were obtained several years ago by Joseph Weber of the University of Maryland, but unfortunately, no one else has been able to duplicate his findings. The chief problem seems to be the extreme weakness of the waves. Even though most scientists are now convinced that the elusive waves do exist, many doubts about Weber's findings have been raised.

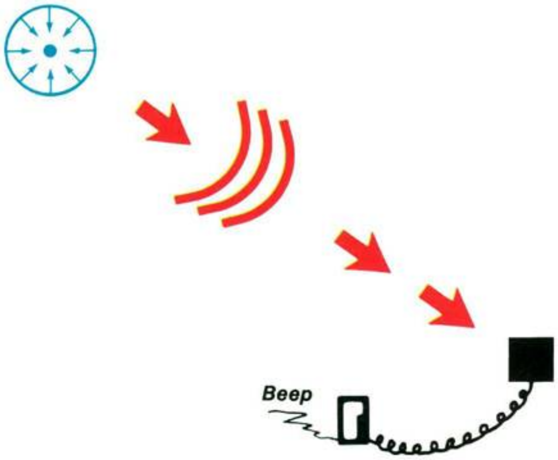
Because gravity waves are essentially moving force fields, they are able to induce minute strains in the objects they encounter. These in turn produce vibrations which can be detected by various means. But if all matter responds to gravitational forces, then everything should vibrate equally, including the attached instrumentation and even the observer. This would indeed be the case if the wave were acting on everything in the same way. But when the antenna is made large enough, different parts of it will respond to different parts of the incident wave, producing unequal vibrations and hence relative motion between different parts of the detector. It is only by means of these relative motions that gravity waves can be detected.

The simplest type of detector, called a *free mass detector*, consists of two bodies floating freely in space, such as Earth and the Moon. The passage of a wave perpendicular to the straight line between the masses will induce minute vibrations in both, resulting in slight variations in their separation distance. The waves would be detected by monitoring these variations. The experimental difficulties here are enormous.

The second type of detector, the *almost-free mass detector*, is very similar, except that the masses are physically suspended in some way. This type of antenna would be practical for earthly installation, while the free mass type could only work in space. A laser device, or perhaps a piezoelectric crystal (which changes its electric properties when stressed) sandwiched between the two vibrating masses, might be employed to monitor the wave's passage.

Most of the experimental work done so far has used a third type known as a *resonant detector*. This consists of a large aluminum cylinder with a network of piezoelectric crystals bonded around its girth. The cylinder is then suspended by a wire, and further acoustical filtering methods are employed to shield it from unwanted interference caused by people, cars, and other external stimuli. Even nearby electromagnetic radiation may cause trouble, requiring further precautions to be taken. Finally, the whole thing is placed inside a vacuum chamber to eliminate even the tiny vibrations caused by bombarding air molecules!

The resonant properties of the antenna are useful because the gravitationally induced vibrations are often too small to be resolved over a reasonable length of time. If the resolution time of the antenna is longer than the actual duration of the bursts, a non-resonant detector won't pick them up at all. In a resonant antenna, the vibrations continue to resound for a period longer than the actual duration of the burst, just as a bell continues to vibrate after it has been struck. This effectively

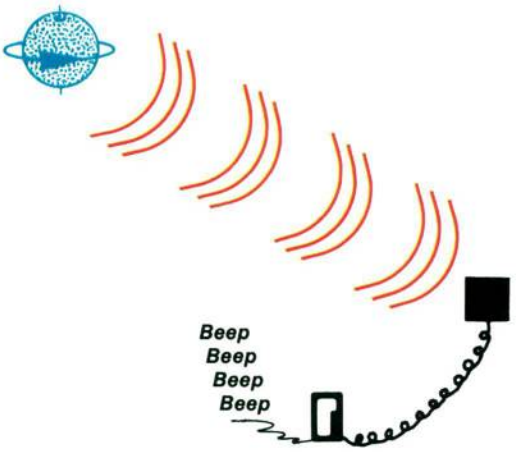


A collapsing mass would produce a single strong blast of gravity waves.

lengthens the resolution time, allowing weaker bursts to be detected.

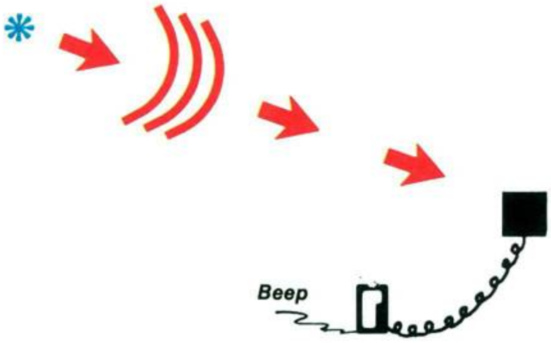
An additional feature of a resonant antenna is that the amplitude of the vibrations caused by the wave need not be larger than the fluctuations in amplitudes due to temperature during the period of observation. Since resonance effectively lengthens resolution time, the result is a "smoothing out" of these thermal fluctuations, making them less troublesome than they would be otherwise. The only problem is that resonant antennas are most sensitive at only one frequency. Only the energy of a wave of that particular frequency can be determined; all other information about the signal is lost. Ideally, an antenna responsive across a wide range of frequencies (a "broadband" antenna) is desired, but as bandwidth increases, resolving time decreases, so a bargain must be struck somewhere.

The antenna used by Weber in his initial work consisted of an aluminum cylinder about 5 feet in length, 3 feet in diameter, weighing about a ton, and tuned to a frequency of 1661 Hz. His system was capable of detecting relative motions as small as one part in 10^{16}, or about 1/100 the size of an atomic nucleus over the total length of five feet. Two such antennae were used, one in Weber's Maryland laboratory, and the other at the Argonne National Laboratory in Illinois. Since each was independent and not subject to the extraneous "noise" which might be received at the other location, coincident peaks recorded by the two might be evidence of a passing gravity wave. Since some of these coincidences probably arose only by chance, additional means were taken to screen out such accidents. In this way, Weber recorded several coincidences per day, on the average, over a period of several months.



A rapidly rotating mass would produce a continuous stream of gravity waves.

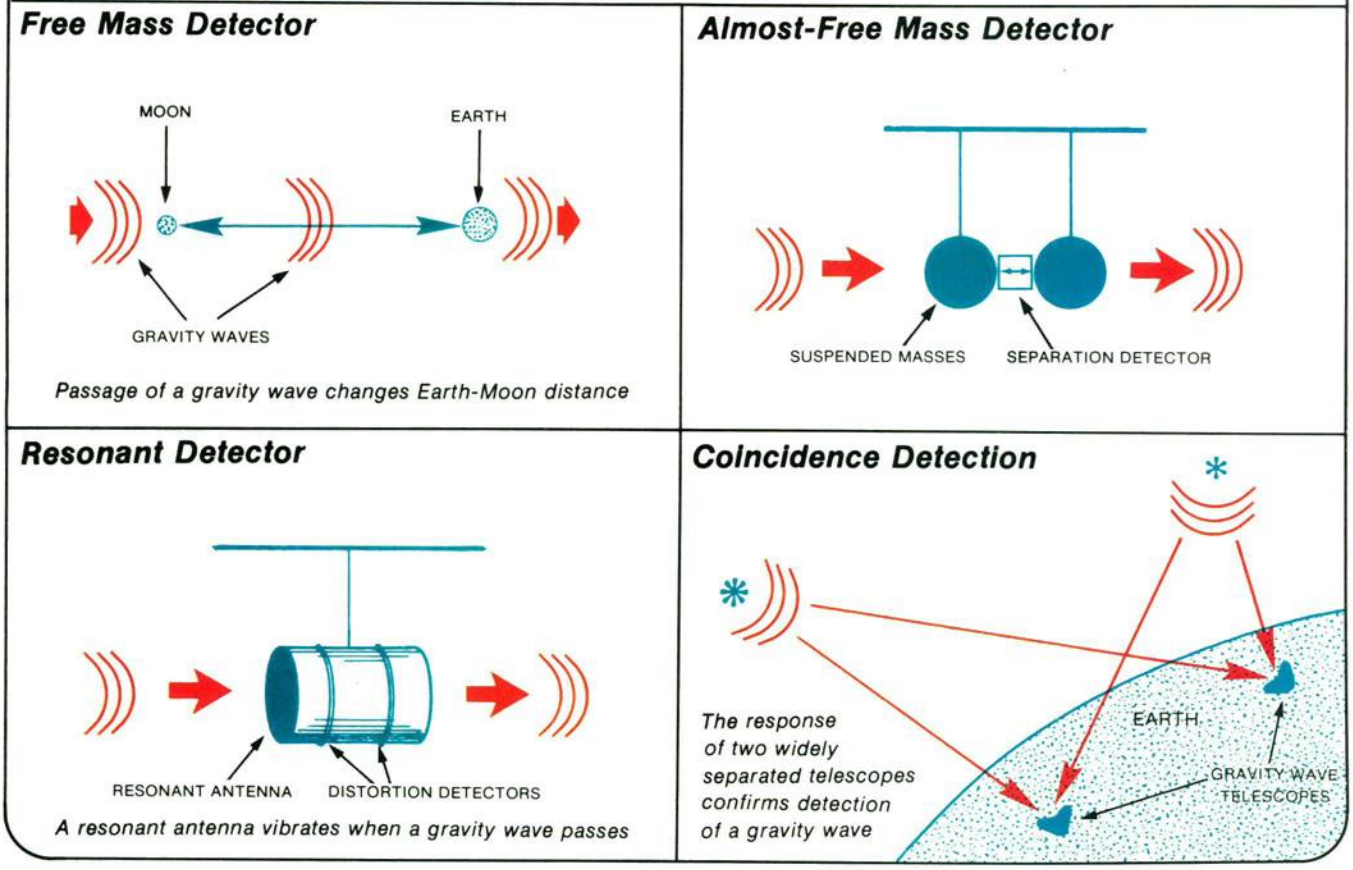
Various other attempts have been made, and continue to be made, by other experimenters. Some have used Weber's type of detector, others have not. Among these other methods was one using a laser beam split in two, with each beam bouncing back and forth between two sets of mirrors. The mirrors were attached to masses which would jiggle in response to a passing wave. Upon recombination of the two beams, a destructive interference pattern would result if they were out of phase with each other, as should happen if the passage of a gravity wave were being detected. Other schemes have used the Earth itself as a detector by monitoring seismic activity. Yet another setup, used by Vladimir Braginsky in the USSR, attempted to measure small changes in capacitance of a device caused by fluctuations in the gap between two metal plates. The list continues, but none of these attempts have yielded conclusive results. It appears that the era of gravity wave astronomy will have to wait until the practical aspects of detector technology can catch up to the theoretical developments in the field.



An exploding mass would produce a single strong blast of gravity waves.

But assuming, for the moment, that Weber's results were real, what do they imply? When he plotted the intensity of his peaks against the sidereal time of their reception, he found a high correlation with radiation coming from the direction of the galactic center. According to his calculations, perhaps 1000 solar masses or more per year were being transformed into gravitational energy and radiated away. Something is clearly wrong here, because this would mean the Galaxy should have burned out long ago. Perhaps the data are off, or perhaps we just don't understand these things well enough to explain them properly. Another explanation, put forth by Charles Misner and his colleagues at the University of Maryland, suggests that a huge black hole of perhaps 10 million to 100 million solar masses is rotating at the galactic center. A lighthouse-like beacon of highly concentrated gravitational radiation is supposed to be sweeping out a path in the galactic plane as a result. This beamed radiation would fool everyone into thinking that a much more powerful radiation source exists than actually does. Not everyone agrees with this explanation, of course, or even that a rotating black hole could do what Misner says. Yet, the idea ties in with Rees' proposal about galactic black holes. One day, maybe soon, we'll know.

GRAVITY WAVE "TELESCOPES"



Free Mass Detector

Passage of a gravity wave changes Earth-Moon distance

Almost-Free Mass Detector

Resonant Detector

A resonant antenna vibrates when a gravity wave passes

Coincidence Detection

The response of two widely separated telescopes confirms detection of a gravity wave

What are the possibilities for a second generation of gravity wave detectors with a greater sensitivity? Improvements in Weber's basic design would be a first step. Such improvements could include cooling the cylinder down to near absolute zero to remove as much thermal interference as possible. One proposal, put forth by William Hamilton of Louisiana State University, calls for a supercooled five-ton aluminum cylinder floating on an invisible magnetic cushion. The magnetic field would be generated by a current circulating in a niobium-titanium coating on the cylinder's supercooled bottom, and would provide an acoustically well-insulated detector. Other designs call for materials other than aluminum. Materials such as germanium, sapphire, silicon and niobium would be far superior, because vibrations induced in them would resound for a longer time. The *Q* of the material, which is the ratio of the energy stored in the material to the amount lost per cycle of vibration, is the critical factor here. Clearly, we need instruments with as high a Q as possible. Present detectors have Qs ranging up to one-half million, but future designs could have Qs ranging from 60 million to one billion, resulting in that much greater sensitivity.

Hamilton has also suggested a superconducting ring in which a circulating current would set up a magnetic field perpendicular to the ring's plane. A passing gravity wave would distort the ring's shape slightly, producing a change in the magnetic flux which could be measured. Improvements in the laser beam-type detector have also been proposed, one of which calls for the two beams to bounce back and forth 600 times between the mirrors before being recombined. A great enhancement in sensitivity should result.

Finally, one of the most far-out schemes, proposed by Kip Thorne of the California Institute of Technology, and Braginsky, would involve measuring the Doppler shift of a radio beam sent out from Earth and transmitted back by receding interplanetary spacecraft. The frequency of the detected wave would depend upon the craft's distance from Earth. Most of the Doppler shift would, of course, be due to the craft's recessional motion. A small part, though, would be due to variations in the craft's distance caused by gravitationally induced vibrations. Sensitive means could measure this tiny part.

Astronomy has certainly come a long way since the days of Galileo's first telescopic observations. With the advent of new technologies and space-based observations, practically the entire electromagnetic spectrum is open to us today. Now it is time to think about the possibilities of a whole new frontier — gravity wave astronomy.

Robert Pinheiro is a mathematician and professional statistician. He has long had an interest in relativistic astrophysics and cosmology.

Jupiter Fly-By!

Voyager 1
March 5, 1979

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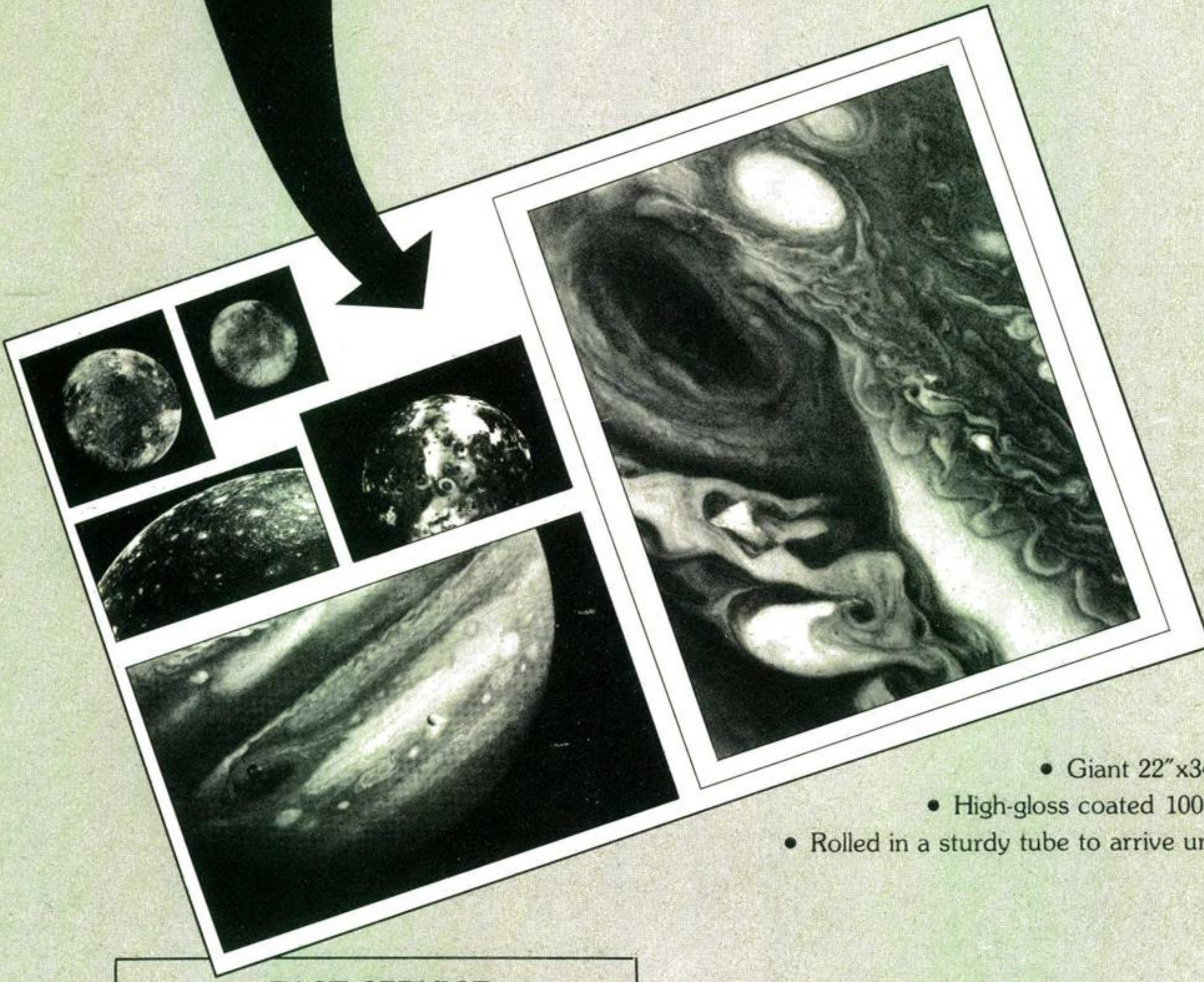

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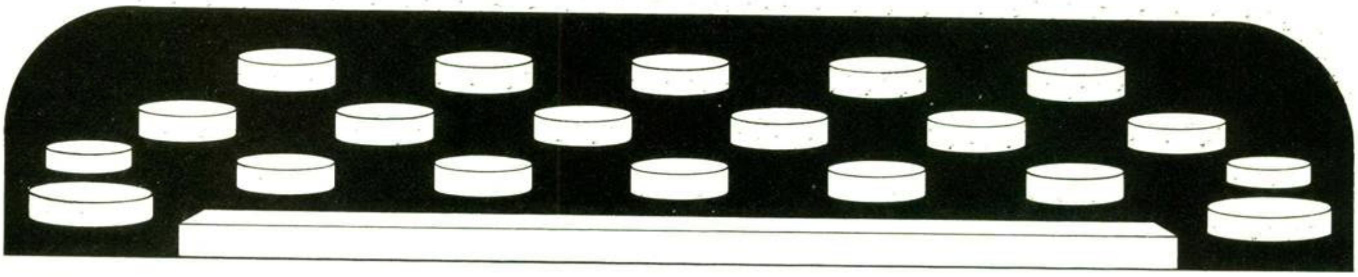


OOOPS!

Several readers have written in to mention that formula 5 in the box on page 10 of the April issue ("Do-It-Yourself Encounter Predictions") is incorrect. The equation should have read: New magnitude = Mag. + (5 × log [Min. dist./dist.]).

Due to an error, the John Clark posters advertised in May 1979 ASTRONOMY were sized at 22"x 34". The correct poster size is 22"x 32".

NEBULAR FILTER UPDATE

The update article on Nebular Filters originally scheduled for this issue will appear in the August 1979 issue. Several manufacturers have recently introduced new model filters, and to allow time for proper testing, we're postponing the update.

Sir / In the formula for local sidereal time given in the December 1978 Equipment Atlas ("How to Calculate Horizon Coordinates"), the constant K is used. The values of K were given for 1978 to 1981; how do you get K for years beyond?

DOUGLAS GOUDIE
Southfield, MI

Mr. Goudie / The constant, K, you mention can be derived by a formula, given in the **Explanatory Supplement to the American Ephemeris and Nautical Almanac.** *The formula is as follows:*

$GMST = 6^h 38^m 45^s.836 +$
$8640184^s.542T + 0^s.0929T^2$

where:

$GMST$ = *Greenwich mean sidereal time at* 0^h *UT, and*
T = *the number of Julian centuries since Jan 0, 1900.*

In practical terms, you need to know the Julian date of the particular Jan 0 in whatever year you need. (The constant K is the sidereal time, at Greenwich, for Jan 0 of each year.) You then subtract 2415020 (the Julian date of January 0, 1900) from the Julian date for the year you want. Divide the remainder by 36525, and you have the number of Julian centuries passed since Jan 0, 1900. This value is T in the equation above.

Putting in your value of T and working through the numbers (when you compute the 2nd and 3rd terms, you'll have to convert the resulting number of seconds to hours by dividing by 3600 before you add them to the first term), you'll end up with vastly more than 24 hours. So divide the sum of all three terms by 24, discarding the non-decimal part of the answer. Multiply the decimal part by 24, and you get GMST in decimal hours which will be your K value.

Here's an example: The constants K were given through 1981; what's the one for 1982?

Jan 0, 1982 has a Julian date of 2444970, but since the Julian day begins at noon, you must take off one half day from the number to get the value you need, so: 2444969.5. Subtracting 2415020 from this, we get 29949.5. Dividing by 36525, the value for T is 0.819972622.

Going into the equation with this for T, we get:

$GMST = 6^h.646065556 +$
$7084714^s.769 + 0^s.062461789.$

Adding terms 2 and 3:

$GMST = 6^h.646065556 +$
$7084714^s.831,$

divide the last term by 3600 to get hours:

$GMST = 6^h.640065556 +$
$1967^h.976342.$

Adding, and dividing by 24, to get days and fractions of days:

$GMST = 82^d.27593367,$

discard the whole number of days, keeping the fractional part. Multiply the fractional part (0.27593367) by 24 to convert back to hours:

$GMST = 6^h.62240808.$

This, in decimal hours, is the value of K for 1982.

Now, the only problem with this formula is that it will get increasingly in error as the century progresses, but it should hold good enough for general purposes until the turn of the century.

When possible, you should always use the value of GMST printed for each year in the **American Ephemeris & Nautical Almanac** *(currently found on page 12) for utmost accuracy.*

Sir / Would you please inform me as to where I could buy the following items:

1) **New General Catalogue** (and the supplemental **Index Catalogues**)
2) **Messier Catalog**
3) **Herschel Catalog**

A.R. ALLBRITTON, Ph.D.
Gonzales, La.

Dr. Albritton / The **New General Catalogue** *(NGC) has been issued in a revised version including the* **Index Catalogues** *(IC) by J. W. Sulentic and W. F. Tifft. The publisher is the University of Arizona Press in Tucson, and the price is $14.50.*

In the past, the standard source for the Messier list was Kenneth Glyn Jones' **Messier's Nebulae and Star Clusters,** *but this is now out of print (try a library). Other possible sources are:* **Deep Sky Objects** *by Jack Newton [published by Gall Publications, Toronto, Canada; $9.50 (Canadian currency)], and* **The Messier Album** *by J. H. Mallas and E. Kreimer (Sky Publishing, Cambridge, Mass.; $11.95). There isn't a "Herschel Catalog" as such; the* **New General Catalogue** *is the catalog of objects observed by Herschel, but without his numbering system.*

Sir / I would like to get hold of a publication that'll tell me the positions of stars, galaxies, "M-" objects, etc. throughout the year. I understand the **Ephemeris** gives this data for the planets day-by-day, but why not for the other objects?

K. J. ADNEY
George Town, BAHAMAS

Mr. Adney / The reason the **Ephemeris** *lists the coordinates for the planets at frequent intervals is that they're moving! The other celestial objects you mention also move, but their great distance from Earth means that their motion is detectable only after a long time has passed. The best overall source for positions is the* **Observer's Handbook** *published by the Royal Astronomical Society of Canada, 124 Merton St., Toronto, Ontario, Canada M4S 2Z2. It costs $4.00 (Canadian currency), and is a very good buy.*

Sir / You may be interested to know that I have subscribed to ASTRONOMY because of my interest in cave exploration.

I was mildly interested a few years ago when a fellow caver pointed out that Mariner data suggested the existence of lava-tube caves on Mars. I thought little more about "caves in space" until I ran across some 1977 issues of ASTRONOMY. The excellent treatment of the Viking program moved me to action. I ordered a stack of ASTRONOMY back issues, looked up other sources, and contacted the caver who had studied Mariner data.

The result? A list of cave types that may be found on Mars, and a continuing interest in the possibility of finding caves of some sort on other bodies in our solar system. I'll be eagerly awaiting your coverage of other probes.

JIM COURTNEY
Appleton, WI

Behind the Scenes

ASTRONOMY goes electronic

Beginning with last August's issue of ASTRONOMY, we've been an electronic magazine. I'm writing this sitting at a television monitor, watching the words flow across the screen as I tap away at the keys. Gone is the old-fashioned typewriter — at the touch of a key, I can insert or delete letters, words, or whole sentences. At a mere keystroke, I can store everything I see on the screen on a magnetic "floppy disk," then call it up again on the screen days, weeks, or months later for editing or rewriting.

But that's not all — after everything is just right, I can take the floppy disk to our typesetting machine, call up the correct program on its built-in minicomputer, and within a few minutes have these words set in type — in any one of the 24-or-so fonts we have on hand, with almost any size and spacing I want. It's a heady experience and it's changed the way we work here at ASTRONOMY. It's very fast and efficient.

Along with equipment changes are personnel changes too. Katherine King, who has worked on every issue of ASTRONOMY for the last three years, is our new Editorial Administrator. Kathy oversees what we call "copy flow," making sure that new manuscripts are speedily and efficiently evaluated by the editors, edited, typed into the electronic systems, set in type, and thoroughly and accurately proofread. Then, after each issue is printed, she makes sure authors, artists, and photographers get their checks on time. She also handles the necessary red tape of such things as contracts and permissions.

Assisting Kathy and the editors is Dianne Precourt Cuneo. Dianne keeps thousands of files, photos, letters, and maddening details straight. She is the one person, more than any other, who "inputs" (as the jargon now runs) copy into the machines. Dianne inputs "rough" manuscripts from an author into the machine's memory, then Robert, Dewey, or I can edit or rewrite to our heart's content with electronic speed. Dianne is also responsible for keeping track of the many beautiful photo submissions you readers send us each year.

The "word processing" machines have added greatly to our speed and flexibility in bringing you ASTRONOMY. The May issue's long articles on Jupiter and the total solar eclipse would have been difficult, perhaps impossible, without these powerful electronic aids. Not only have they greatly increased our ability to produce ASTRONOMY, but they're a great help in producing ODYSSEY and TELESCOPE MAKING. The latest issue of TELESCOPE MAKING, for example, is 48 pages thick — and that's a lot of copy! Before we had "word processing" we might not have started two new magazines; now they're a reality.

ODYSSEY is AstroMedia's magazine for kids. It's put out by the entirely marvelous Nancy Mack (the Editor, with the round antenna knobs), and Cathy C. Cook (the Graphics Designer, with the conical antenna knobs). ASTRONOMY's editors help out with ODYSSEY, too. Most enjoyable is "The Thoroughly Magnificent Richard and Robert Show." In it, Robert Burnham and I, with the assistance (or hinderance — because he steals the answers) of the Diabolical Dr. D. (played by Dewey Schwartzenburg), show kids simple projects involving astronomy that they can do at home (like measuring the size of the Sun). It's fun and it's crazy.

Nancy and Cathy are a lively duo. "We're just a couple of big kids ourselves," they say, but the rest of us aren't so sure. We think they're real pros to put out such a fine magazine. And I, for one, like the fact that they're getting kids interested in astronomy. ODYSSEY makes planets and stars part of kids' lives, encouraging their natural curiosity.

So here I am, back at the keyboard, plinking away and watching the green letters flow across the screen as I write this. And that's all for this installment of Behind the Scenes....

Richard Berry

Richard Berry
Editor

X-Ray Pictures from Space

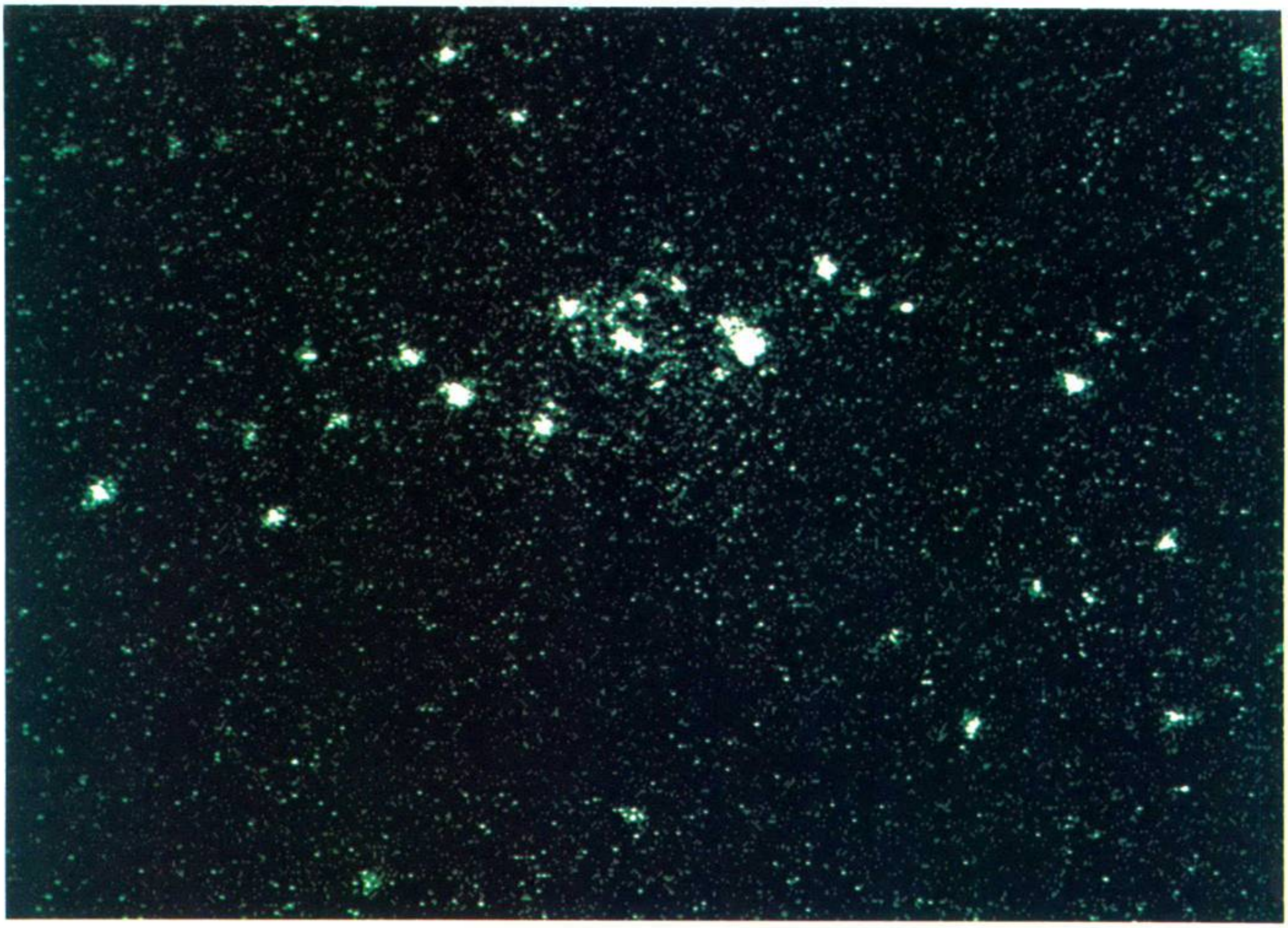
X-ray astronomy, a field only dreamed of a few years ago, has finally come of age. Celestial X-ray observations are only possible from outer space, because the Earth's atmosphere absorbs such high-energy radiation. But now the first telescope capable of producing focused images showing the structure of X-ray objects has been placed in orbit.

The second satellite in the High Energy Astronomical Observatory (HEAO) series has already begun producing amazingly detailed images of cosmic X-ray sources, which are being studied for new clues to cosmic evolution and other astrophysical processes. Previous X-ray satellites have only been able to detect the approximate position and intensity of such objects. Launched November 13, 1978, HEAO-2 has been named the Einstein Observatory in honor of the famous scientist whose theories of space, time, and matter form the basis of much of our understanding of the high energy universe.

Scientists analyzing more than 500 images already received from the Einstein Observatory have seen the brightest, most distant, and most powerful objects yet observed to emit X-rays: quasars estimated to be more than 10 billion light-years from Earth. The intense X-ray emission from the quasars, strange star-like objects that radiate inordinate amounts of energy for their apparently small size, suggests that they may contribute significantly to the widespread low-level background of cosmic X-ray radiation seen throughout the skies. This discovery could have important implications for theories of cosmic evolution, for it could mean that the mass cosmologists calculate would be necessary to "close the universe" is not present in the form of hot gas and may indeed be missing. Such a finding would lend support to theories that the universe will expand forever.

The distant quasars were discovered by Smithsonian Astrophysical Observatory scientists using the high-resolution telescope to make deep-space surveys in its so-called "serendipity mode". The objects appeared as bright point sources in otherwise featureless fields and, when compared with optical charts of the same sky regions, corresponded with some extremely faint visual objects later identified as quasars. Observations of their redshifts were subsequently made by astronomers using the 4-meter Anglo-Australian telescope.

This image of the well-known quasar 3C-273 (lower left) also reveals a previously unknown (and unrelated) quasar nearby (seen at upper right). The "halo" around 3C-273 is an artifact of the imaging system. In this long-exposure image, over 50,000 high-energy photons were counted from 3C-273, while the newly identified quasar registered only 127 photons. Thus the image of 3C-273 has been greatly "overexposed" to bring out the presence of the new quasar, recently identified optically as an object of blue magnitude 18 ± 0.5. Photo courtesy of Smithsonian Astrophysical Observatory/NASA.



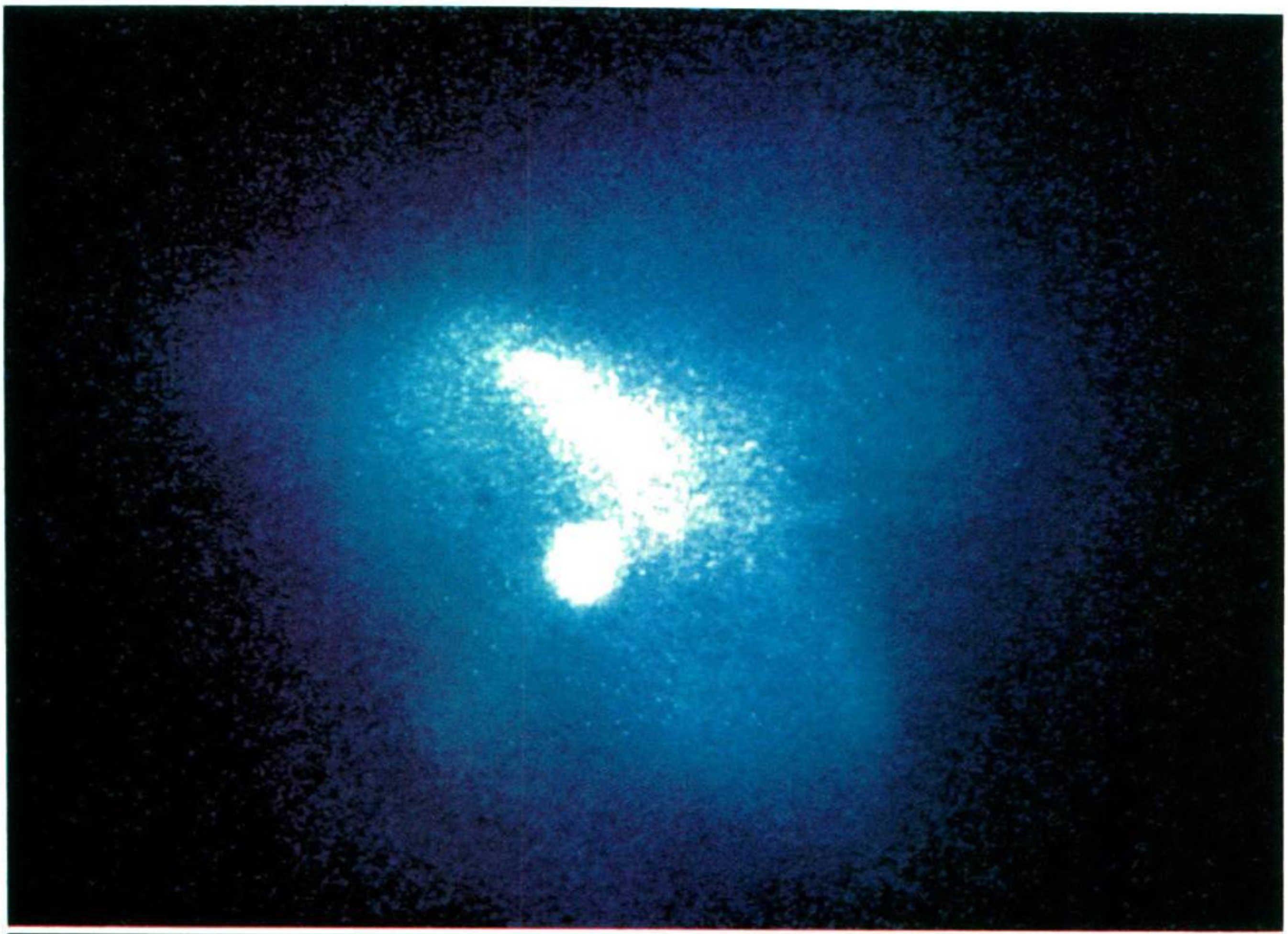
Left: This X-ray image of the gaseous nebula Eta Carinae clearly reveals the exceedingly hot O-type stars imbedded deep within the nebula. Young stars such as these were not expected to be such strong X-ray sources. Astronomers hope that further observations of such stars at X-ray as well as other wavelengths will lead to an explanation of their high-energy emission. Above: Over 70 X-ray sources have been identified by the Einstein Observatory in our neighboring galaxy M-31 (in Andromeda). Some of these are seen in this image of the central region of the galaxy. The source seen here just to the left of the brightest (largest) emission, lies at the exact center of the galactic nucleus, and could possibly be due to the presence of a black hole. Most of the other sources have been identified as X-ray stars or globular clusters. Photos courtesy of Smithsonian Astrophysical Observatory/NASA.

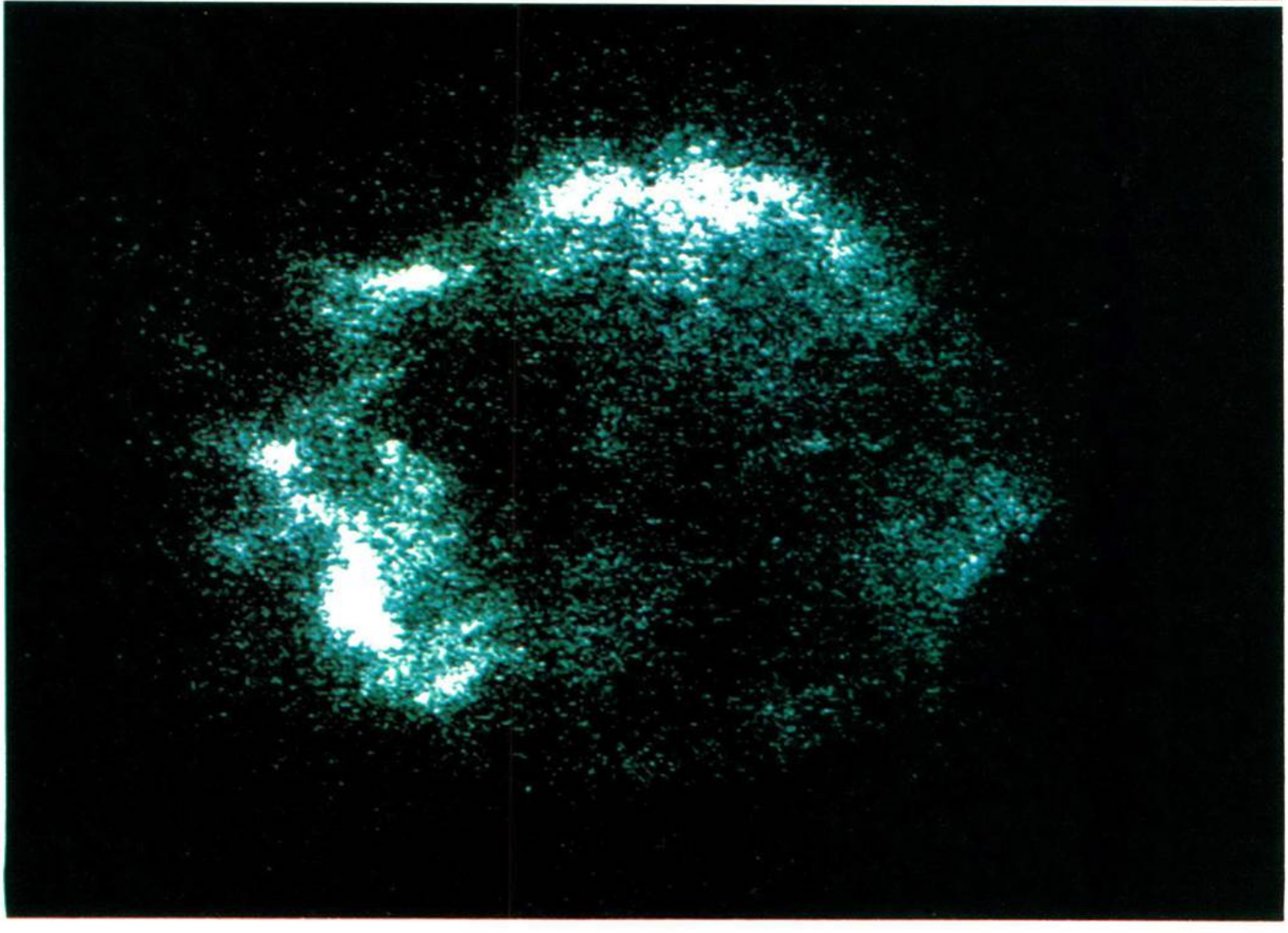
The number of quasars seen by the satellite suggests that much of the "diffuse X-ray background" that seems to permeate the entire sky may actually originate in these objects. Previous experiments had indicated that this background noise was produced by an extremely hot gas pervading the universe. Moreover, estimates of the amount of gas pointed to the fact that it could contribute enough mass to close the universe, that is, to provide the gravitational force needed to prevent eternal expansion into the void. The new results imply that these highly energetic bodies must be emitting a significant fraction of this background emission and, while numerous, the aggregate mass of the quasars would *still* be insufficient to close the universe.

In addition to observations of quasars, the Einstein telescope has observed "normal" stars similar to the Sun, a class of young hot stars with strong X-ray emissions in their outer atmospheres, the remnants of supernovae, "cosmic bursters" in globular clusters, distinct sources of X-ray emission in other galaxies much like our own, and the most distant clusters of galaxies yet observed by any instruments.

The observation of X-ray emission from "normal" stars is expected to provide new clues to understanding the energy processes at work in the Sun. Previously, scientists had been able to study coronal emission of X-rays only on our own Sun. Now, the new observations allow comparative studies which are vital to explaining the mechanism that transports heat from the solar interior to its outer atmosphere.

The new class of stars observed by the Smithsonian team are peculiar O-type stars, which are seen in the gaseous nebula Eta Carinae. These young stars, still in their early evolutionary stages, are buried so deeply in dust and gas clouds that previously they have been detected only by the infrared light radiated by the surrounding cocoons of dust. The detection of X-rays from them is somewhat surprising. Some hitherto unknown mechanism, perhaps magnetic bubbles in their atmospheres, apparently generates this high-energy radiation.





At the other end of the evolutionary scale, several dying stars have been observed as X-ray sources, including the supernovae Cassiopeia A, Tycho, SN1006, Vela X, and the Crab. A supernova occurs when a massive evolving star is no longer able to offset the crushing force of its own gravity through thermal pressure generated by burning nuclear fuel and dies in a colossal explosion. The star first implodes and then explodes, unleashing a tremendous amount of energy in the form of exploding matter and radiation. The expanding material may form a very hot shock-wave when it encounters the surrounding interstellar material.

The Einstein observations of Cas A, Tycho, and SN1006 show a complex X-ray shell structure and unusual spectra, which are being compared to optical and radio data in order to develop a complete picture of the events that followed the supernova explosion.

Before the Einstein Observatory, only silicon and iron line emissions had been identified in X-ray spectra. Now, in the spectra of several of these supernova remnants, thermal emission lines arising from highly ionized states of magnesium, sulphur, argon, and calcium in addition to silicon and iron have been detected. Since heavy element synthesis occurs only in the last stages of stellar evolution culminating in supernovae, the emission is from freshly synthesized material. The abundances measured, which appear to be very similar to solar system abundances, directly confirm the theory that the Sun and planets were formed out of the debris from similar supernovae which detonated billions of years ago.

Another early Einstein observation may contribute to the resolution of a continuing controversy over the nature of the X-ray emission associated with globular clusters of stars. Globular clusters, large spherical conglomerations of stars spread in a halo around our galaxy, have produced one of the more intriguing puzzles of the X-ray era. Intense X-ray sources, some of which switch on and off like cosmic lighthouses, have been observed in several clusters by earlier X-ray satellites. Ambitious theories have been proposed to explain these so-called cosmic bursters, such as the erratic accretion of gas onto a black hole or the presence of a binary system in which one member is a neutron star accreting gas provided by its stellar companion.

Preliminary data from the Einstein Observatory show that the X-ray source in one such globular cluster is located precisely at the center of the cluster. If additional sources continue to be found so close to cluster centers, the sources each will be required to have a mass comparable to at least 30 suns, strongly implying the presence of a huge black hole in the center of these globulars.

The Einstein satellite has also been able to make detailed studies of many normal galaxies and to identify distinct sources of X-ray emission in each. Particularly interesting is the galaxy M-31, a spiral galaxy similar to our Milky Way, which shows dozens of X-ray sources in the central bulge of the galaxy and also strung out along the spiral arms. Previously, other galaxies such as M-31 had been seen only as vague, blurry sources of X-ray emission. Now, with the Einstein telescope, it is possible both to chart the overall X-ray intensity of each galaxy and to map its individual features.

The observation of X-rays from giant clusters of galaxies lying at the farthest distances has important implications for theories of cosmic evolution. In addition to charting the distribution of these massive stellar conglomerations, the largest aggregates of matter known to exist, the observations may reveal the history of their formation. It is still unclear if the clusters of galaxies formed directly from vast gas clouds at an early stage of the universe or if they later got bound together by gravitational processes, somehow.

The Einstein Observatory has also discovered X-ray emission lines from a host of other exotic astrophysical systems ranging from hot stars, through binary systems containing white dwarfs, neutron stars or black holes, to the gas which permeates clusters of galaxies. The implications of these new measurements on the detailed modeling of such systems are only starting to emerge. In addition, the Einstein Observatory's sensitivity to X-ray line emission makes the failure to detect line features in other sources particularly significant. Quasars and Seyfert galaxies, for example, appear to lack any significant emission features, as would be expected if the X-radiation is non-thermal in origin.

The Einstein satellite has been operating only four months, but already it has doubled the number of known X-ray objects in the universe. More important, the rapid increase in the sensitivity of X-ray telescopes in little more than a decade is comparable, according to one of the project scientists, Riccardo Giacconi, to "the 350-year evolution of the optical telescope from Galileo's crude refractor to the 200-inch Palomar reflector." Indeed, the Einstein Observatory has given X-ray astronomers the capability to produce images of the heavens with a sensitivity and accuracy equal to the best instruments in both optical and radio astronomy. As the pictures accompanying this article demonstrate, they are often beautiful images as well. ◆

Top: The X-ray image of the Crab Nebula is dominated by the emission from the pulsar whose explosion gave rise to the present nebula. The pulsar, a rotating neutron star with a strong magnetic field, accelerates atomic particles to very high velocities until they are expelled into the surrounding medium. X-rays are also observed where these high-energy particles interact with the expanding nebula. Bottom: Extremely high temperatures are revealed in this X-ray picture of the Cassiopeia A supernova remnant. The expanding gas from the original explosion appears as a shell as it rushes outwards into the surrounding interstellar material. Photos courtesy of Smithsonian Astrophysical Observatory/NASA.

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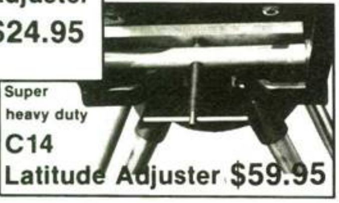

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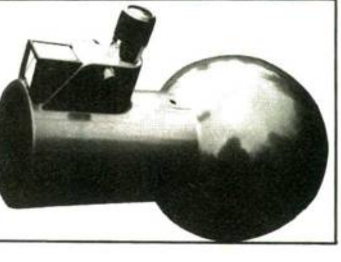

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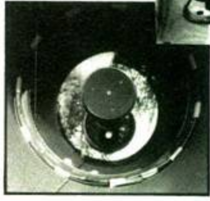

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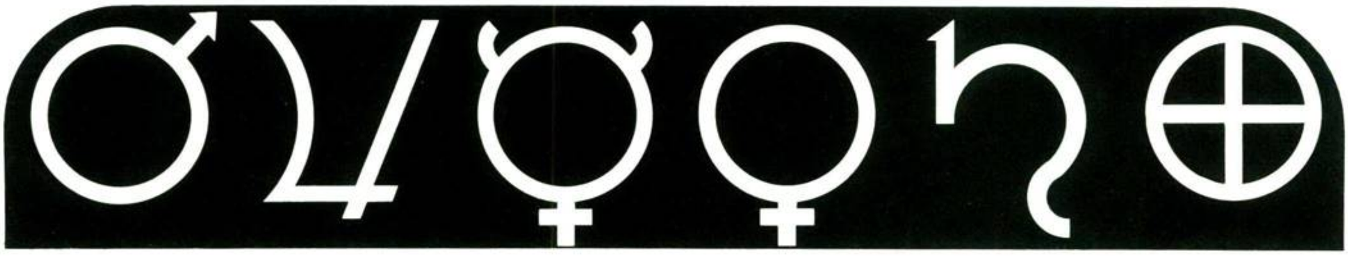


The Opposition of Neptune

During June, the planets are all placed where you can see them relatively well — though by the end of the month, changes are imminent. Jupiter and even Saturn are being crept upon by the Sun, Mars first reappears clearly in the morning sky, and Venus is slipping away. All in all, it's a time to be wrapping up some observations and starting new ones.

Mercury

Mercury is an evening planet this month and for most of next as it coasts out to the east of the Sun, heading for a favorable elongation on the 3rd of July.

On page 32, you'll find a diagram showing the path of Mercury relative to your northwestern horizon. The time for the diagram is half an hour after the Sun has gone down. The positions were computed for someone watching from 40° north latitude, but the diagram will closely approximate the visual aspect for most North American readers.

This elongation shows clearly how Mercury's maximum elevation needn't necessarily coincide with the elongation date. Its greatest visibility will be about 10 days before elongation, so you'll see it most easily during the last week of June. The disparity between elongation and maximum elevation dates comes about chiefly because the angle Mercury's orbit makes with the horizon is low; the farther north you're observing from, the greater the effect.

Anyone with at least a small telescope should be able to pick out Mercury's phases during this apparition. Observing it every clear evening during June will show rather rapid changes in the disk's size and shape.

Unless you have a moderately wide-field finderscope on your instrument, you'll probably find Mercury most easily if you use binoculars first to locate the planet, and then aim your scope. Don't attempt very high powers; use just enough to make out the form of the disk. If you try great magnification, you'll only be disappointed. The distortions caused by our atmosphere will create a wiggly, boiling image.

Venus

Venus is steadily moving farther away as it heads for the far side of the Sun. The planet's featureless disk looks almost completely round now, and extends only a diminutive 10½ seconds of arc.

At magnitude -3.3, it's as dim as it'll ever get, though the decreasing contrast between the planet and the brightening twilight sky will make it progressively less visible as it moves nearer the Sun. Now about 5° high half an hour before sunrise, you'll still be able to find it rather easily, provided you look to the east where the view is uncluttered by houses and trees.

Earth

Summer begins for the northern hemisphere this year at 23^h56^m UT on June 21st, when the Earth's north pole is tipped 23° 27′ toward the Sun.

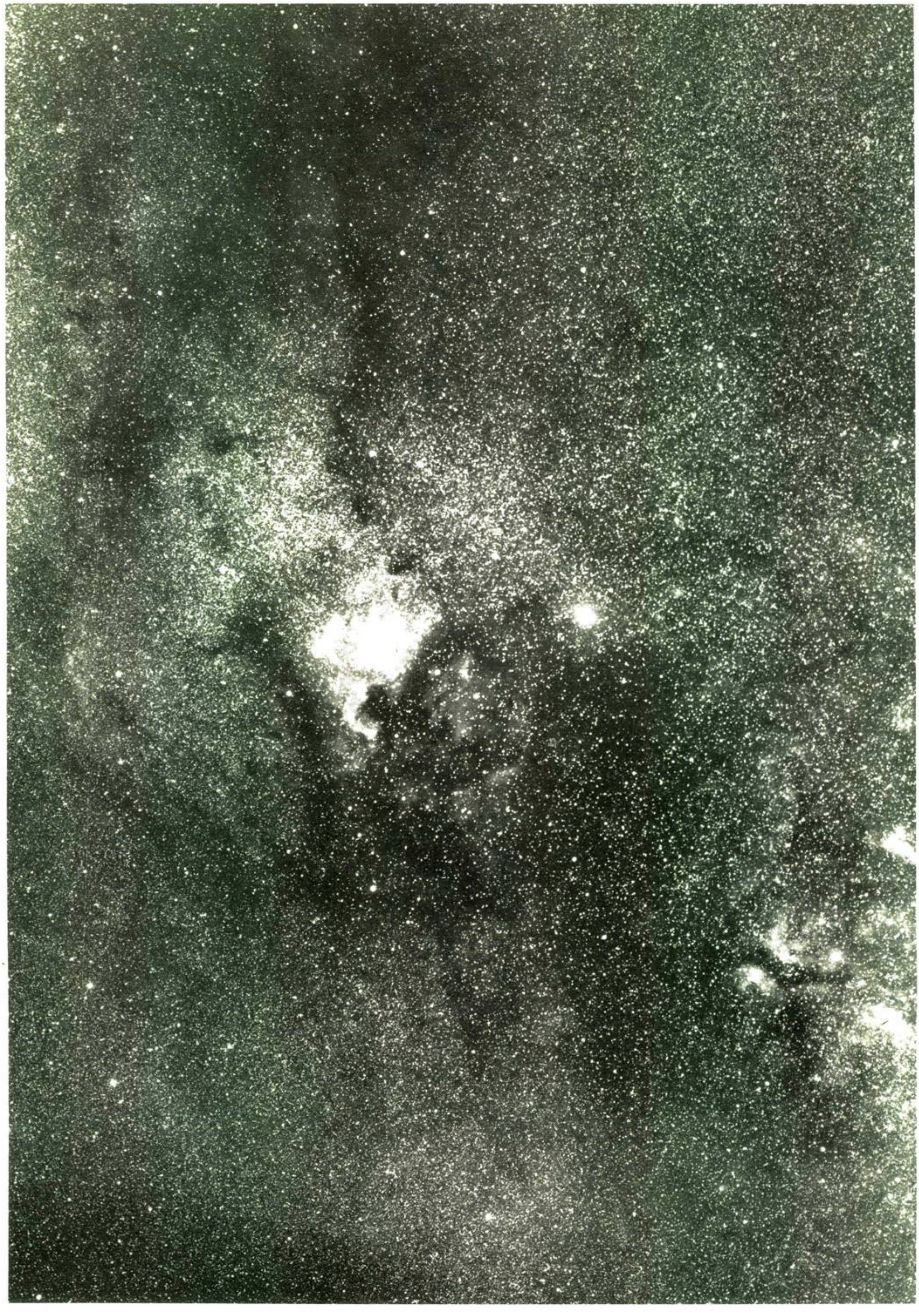
Moon

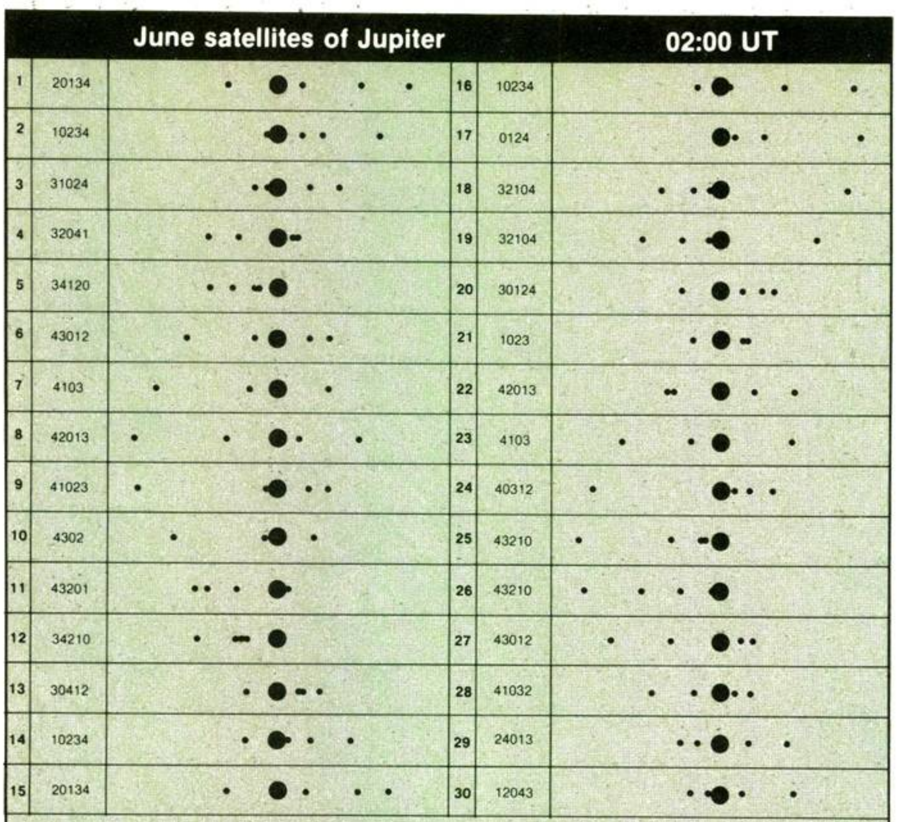
The Moon will occult Aldebaran on the 22nd of this month, the event being visible from almost all of the U.S. and Canada. The areas outside the limits for the occultation are in Texas south of Corpus Christi and in the Florida peninsula south of St. Augustine. What makes this occultation different from the other recent ones is that it happens during full daylight.

The Moon at the time will be 2 days from new phase, in shape a slim waning crescent about 4% lit. The times of disappearance will begin around 15^h30^m UT in California. As the edge of the Moon moves eastward across the sky, the times of occultation will steadily increase:

15^h40^m	*UT*	*Oregon*
15^h45^m		*New Mexico*
15^h54^m		*Vancouver*
15^h55^m		*Colorado*
16^h12^m		*Edmonton*
16^h15^m		*Texas*
16^h23^m		*Winnipeg*

Deneb, the North America Nebula, and the head of the Cygnus rift all stand out magnificently in this red-light photograph by A.K. Parizek. He used 103aE plates hypersensitized with hydrogen. The lens was a 12″ focus Ektar set at f/5.





The four major satellites of Jupiter orbit the planet in periods ranging less than 2 days to 17 days. You'll see them change position from night to night. This table shows the approximate position of the moons each night. The column at the far left shows the date; the second column gives the names of the moons (Jupiter = 0, Io = I, Europa = 2, Ganymede = 3, Callisto = 4). The third column shows the satellites' positions as they appear through an inverting telescope; south is at the top.

16^h25^m	*Illinois*
16^h50^m	*Toronto*
16^h50^m	*Alabama/Georgia*
17^h00^m	*Montreal,* *Washington, D.C.,*
17^h17^m	*Massachusetts* *Halifax*

Because the disappearance is a daylight one, it will naturally be difficult to observe, though by no means impossible. You might not think so, but you'll actually be able to pick out Aldebaran. You will need a very clear day with little or no haze, and using a red filter like the Kodak 25A to darken the sky will help a lot.

Aldebaran will be 1^h27^m of R.A. to the west of the Sun and 6°50′ to the south of it. If you have trouble locating the Moon in the sky, center the Sun in your field of view (use projection methods or a *tested, visually-safe* aperture filter!) and then offset the required amounts. You'll then find the Moon and Aldebaran in a low to medium-power eyepiece.

First quarter: June 2nd, at 22^h37^m UT, in Leo. Full: June 10th, at 11^h55^m, in Scorpius. Last quarter: June 17th, at 5^h01^m, in Pisces. New: June 24th, at 11^h58^m, in Orion. Apogee: June 1st at 17^h and June 29th at 11^h; Perigee: June 13th at 16^h.

Mars

Mars' visibility will improve a lot during June: on the 1st, it'll be 9° high at azimuth 78° half an hour before sunrise. By the 30th, the altitude at the same time will be fully 10° higher, the azimuth remaining essentially constant.

On the 21st, the Moon will lie about 5° to the southwest of Mars, with the Pleiades about the same distance to the northeast of the little planet. Use binoculars; they're the most useful optical aids for watching this sort of thing.

For the telescopist, Mars is still a disappointment, offering little detail on its 4.3 arc second disk. A few patches of dark may be seen and perhaps the polar cap will betray its presence, but there's not a whole lot to see right now. Someone once said, rather truthfully, that Mars was only available for inspection for 4 months every two years.

On Mars, the season corresponding to our terrestrial January is well in progress since the martian northern hemisphere is tipped away from the Sun.

Jupiter

This is the last full month to make jovian observations before the glare of the Sun creeps out to engulf the planet. Half an hour after sundown on the 1st of the month, Jupiter will be 35° above the horizon and almost due west, but by month's end, the elevation will be only 15°.

The Galilean moons (or should we call them "planets" from now on?) continue to play their games of hide and seek around Jupiter, and you'll have a chance to join in on many days this month. See the short table on this page where we've tabulated some phenomena for you.

Remember though, that not everyone will be able to see all these transits, occultations, and disappearances favorably. For example, people on the west coast will see Io's eclipse reappearance on the 4th (at 2^h11^m UT) while the Sun is still up. However, those on the east coast will see the event over an hour after their sunset.

The other notable event for Jupiter

Jovian Satellite Phenomena

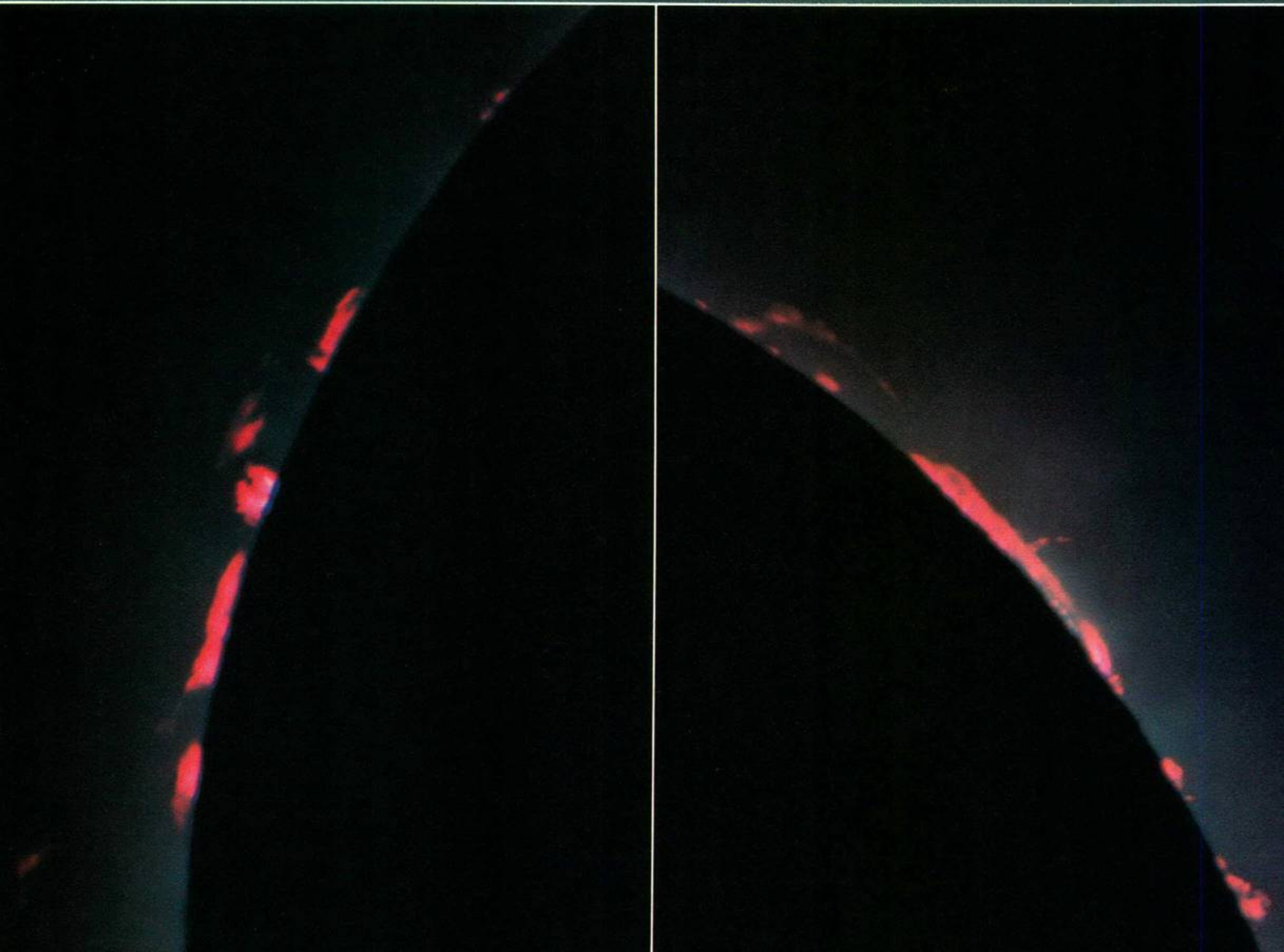
Satellite	Event	Date	Time
Io	Tr B	3	1:31
	Sh B		2:33
	Tr E		3:48
	Sh E		4:50
	Ec R	4	2:11
	Oc D	11	0:52
	Ec R		4:06
	Oc D	18	2:52
	Ec R		6:00
	Tr B	19	0:01
	Sh B		0:51
	Tr E		2:18
	Sh E		3:09
	Ec R	20	0:29
	Oc D	25	4:52
	Tr B	26	2:01
	Sh B		1:59
	Tr E		4:19
	Sh E		5:04
Europa	Tr B	7	2:42
	Sh B		4:40
	Tr E		5:32
	Ec R	9	1:44
	Oc D	23	2:27
	Tr E	25	0:27
	Sh E		1:59
Ganymede	Tr E	10	1:19
	Sh B		1:36
	Tr B	17	2:04
	Ec R	28	3:22
Callisto	Tr B	21	1:27
	Tr E		6:13

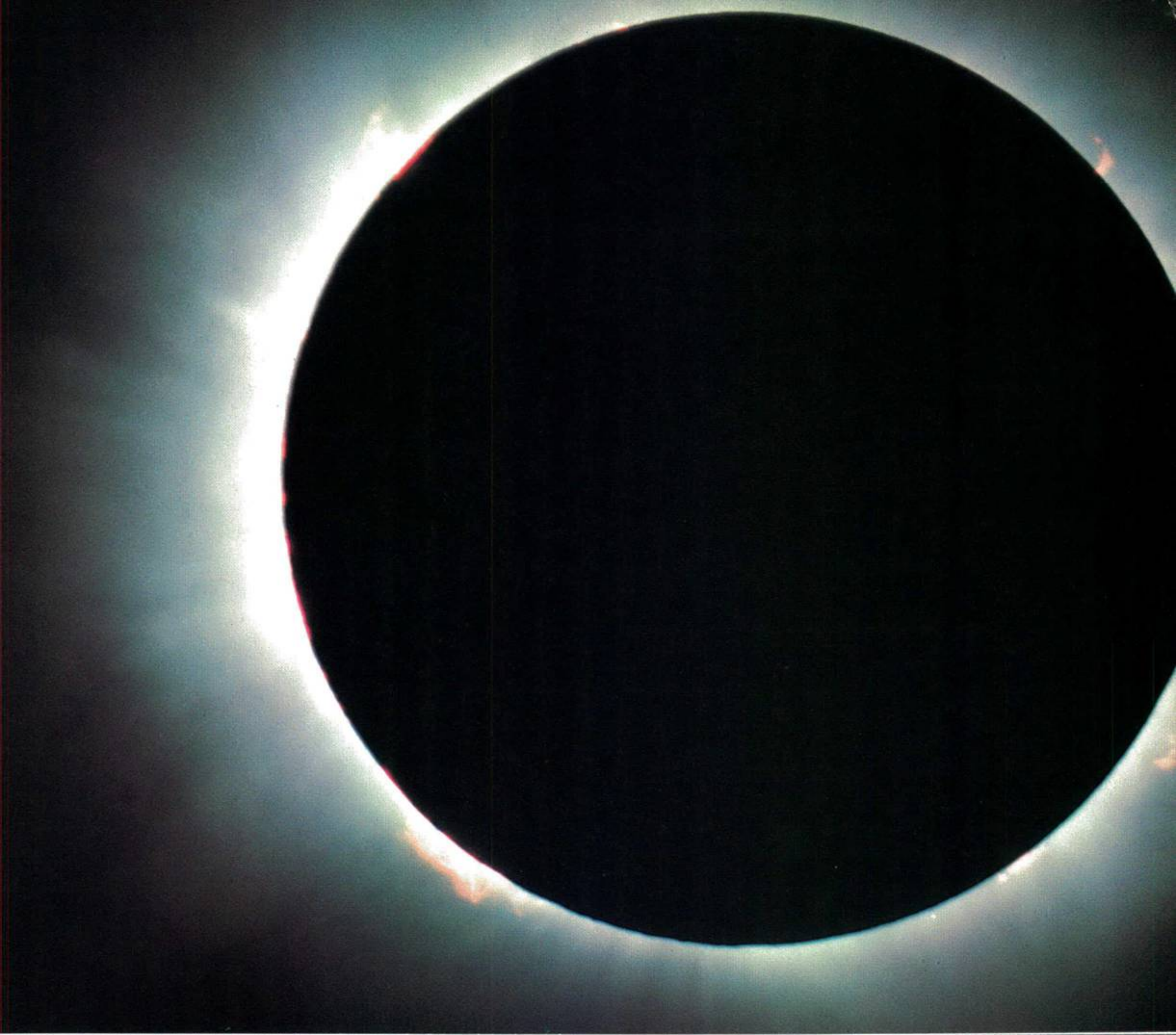
The symbols in the second column are as follows: Tr = transit of moon, Sh = transit of moon's shadow, Oc = occultation of moon by Jupiter, Ec = reappearance of moon from eclipse, B = means beginning, E = end, R = reappearance, and D = disappearance. The dates and times are in UT.

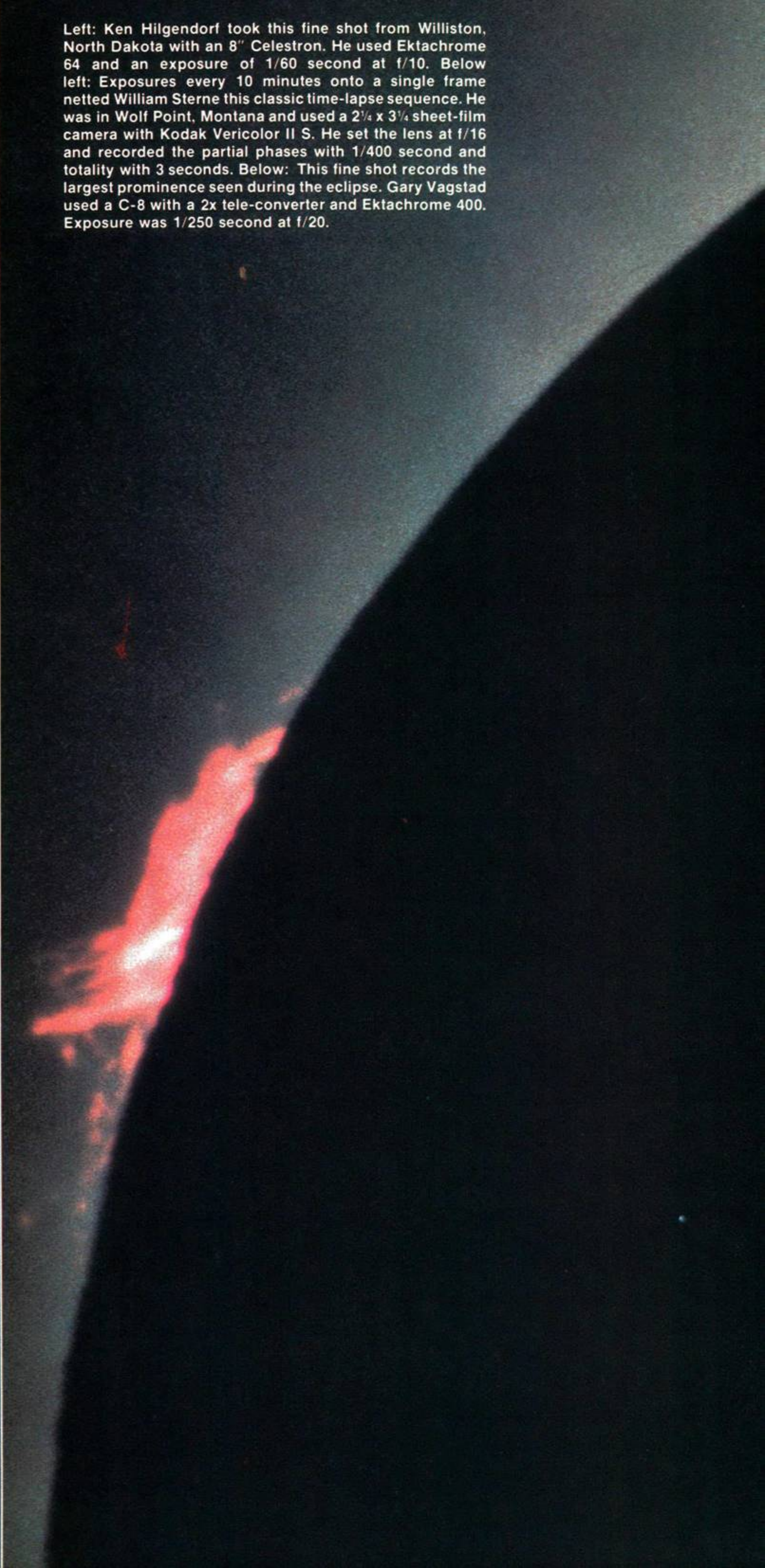
Eclipse Roundup

Last month, ASTRONOMY presented many fine photographs of the magnificent eclipse of February 26, much the view you might have had if you traveled to see totality. The emphasis was on the whole corona, though of course, there was a remarkable close-up. This month, we concentrate on the dramatic sights that you might have missed in all the hurry and excitement — the details of the prominences, the beautiful flash spectrum, and the complex twisted structure of the corona.

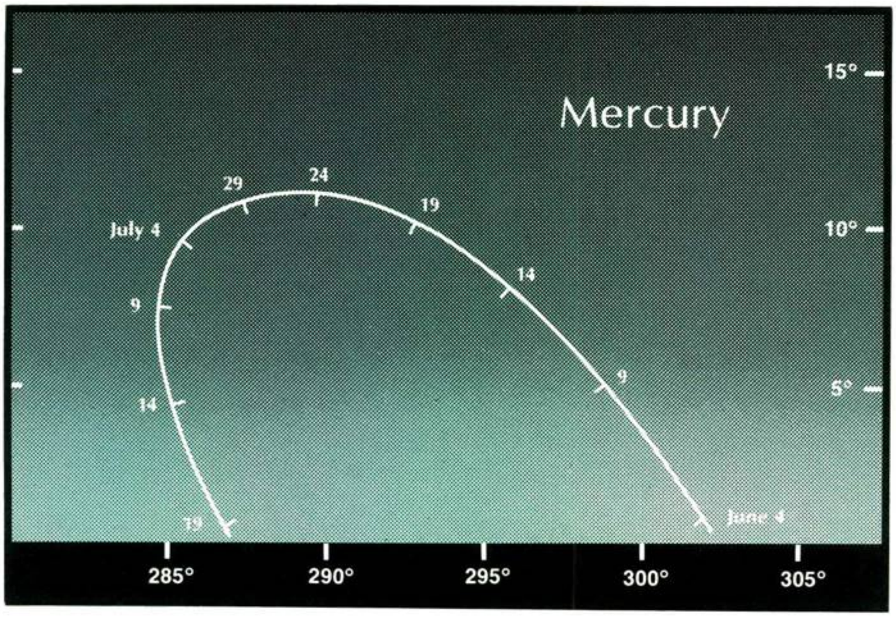
Above: David Roles was in Arlborg, Manitoba when he took this photo combining the flash spectrum of the chromosphere with the eclipsed Sun and corona. Below left and right: Ron Dilulio used a Celestron 8, 200 ASA film, and 1/125 second exposure to get these prominences.







Left: Ken Hilgendorf took this fine shot from Williston, North Dakota with an 8" Celestron. He used Ektachrome 64 and an exposure of 1/60 second at f/10. Below left: Exposures every 10 minutes onto a single frame netted William Sterne this classic time-lapse sequence. He was in Wolf Point, Montana and used a 2¼ x 3¼ sheet-film camera with Kodak Vericolor II S. He set the lens at f/16 and recorded the partial phases with 1/400 second and totality with 3 seconds. Below: This fine shot records the largest prominence seen during the eclipse. Gary Vagstad used a C-8 with a 2x tele-converter and Ektachrome 400. Exposure was 1/250 second at f/20.



Mercury's path in the evening sky is shown here for June and half of July. The time is 30 minutes after sunset, and the observer's latitude is 40° north.

Universal Time

Astronomers the world over use an unambiguous system of time reckoning based on a 24 hour clock, called Universal Time (UT). Times given in Sky Almanac are in UT unless noted otherwise. To convert UT into your local daylight time, subtract the following number of hours for each time zone: EDT, 4; CDT, 5; MDT, 6; PDT, 7; Alaska and Hawaii, 9. For example, if an event is to happen at 03:00 hours UT on June 7, then the time in EDT would be 11 p.m. June 6. Likewise, 03:00 UT on Sept. 2 becomes, in PDT, 8 p.m. on Sept. 1.

Upcoming Events for July

2	First Quarter Moon
3	Earth at aphelion Mercury at eastern elongation
9	Full Moon
14	Mercury at aphelion
16	Last Quarter Moon
24	New Moon
27	Saturn 2° north of Moon
28	Delta (δ) Aquarid meteors
31	Mercury at inferior conjunction

The movement of Jupiter into the twilight will make for some pretty arrangements and conjunctions with foreground objects this month, especially around the time of Mercury's elongation.

There's an occultation of Aldebaran on the 20th, but it's not visible from North America.

The Delta Aquarids are a moderately strong shower, having 20 per hour, and the activity is well spread out over several weeks. The Moon will be near first quarter on the nominal date of maximum, so the shower won't be interfered with.

this month will be its passage past the Beehive Cluster (M-44). At its closest, on the 12th, Jupiter will be just over a half degree south of the cluster's center. The contrast of the bright, -1.4 magnitude planet with the dimmer spray of cluster stars will be very delightful. Binoculars or a low power RFT (rich-field telescope) will show the conjunction best. But don't feel left out if weather prevents you from watching on the 12th; the passage is hardly a rapid one and looking at any time over the course of the month will give you a pleasant view.

Saturn

For Saturn, too, the Sun is beginning to encroach on its domain. Saturn will remain visible in the evening sky until about mid-August, which means that you should get in what observing time you can, now.

On the 2nd, a first quarter Moon will pass to the south of Saturn, missing it by about 2°. Since the time of closest approach (16 hours UT) comes during daylight for North America, you'll have to wait until nightfall to see the conjunction. By that time, of course, the Moon will have moved farther to the east, since it moves through its own diameter in about an hour, and you'll have to observe with naked eye to see the two together.

Uranus

Uranus is one of those planets that presents rather little to the telescope user, since about all that's visible is a small, greyish dot, 3.8 arc seconds in size. Under moderate powers, you can tell that it isn't a star, but not a great deal more is apparent. It's a cold, dim world, circling the Sun placidly some 1 6 light-hours from it.

Uranus has a ring system, and 5 known satellites, with probably many more moons as yet unfound. Three of its moons are visible in large amateur scopes (12" or larger): Ariel (U I) at 14.4 magnitude, Titania (U III) at 14.0, and Oberon (U IV) at 14.2. The other two moons are dimmer: Umbriel (U II) at 15.3 and Miranda (U V) at 16.5.

Because we are looking "down" on the uranian system with its north pole directed almost at us, the moons are seen to circle around the planet in ellipses, with the northern and southern elongations being the greatest.

Readers with large instruments may want to try looking for some of the satellites, so here's how: Ariel's maximum elongation (north and south) this month is about 15" of arc, the minimum (east and west) being 13". Ariel circles Uranus every 2 days 12.5 hours. Northern elongations happening during darkness come on the 24th (at 4^h55^m UT) and on the 29th, at 5^h55^m UT. (Oberon is brighter than Ariel, but its elongations are inconvenient during June.)

For Titania, the orbital period is 8 days 16.9 hours, and a northern elongation comes on the 11th, at 7^h10^m UT. Titania's north and south elongations are 34", while the east and west ones are 30".

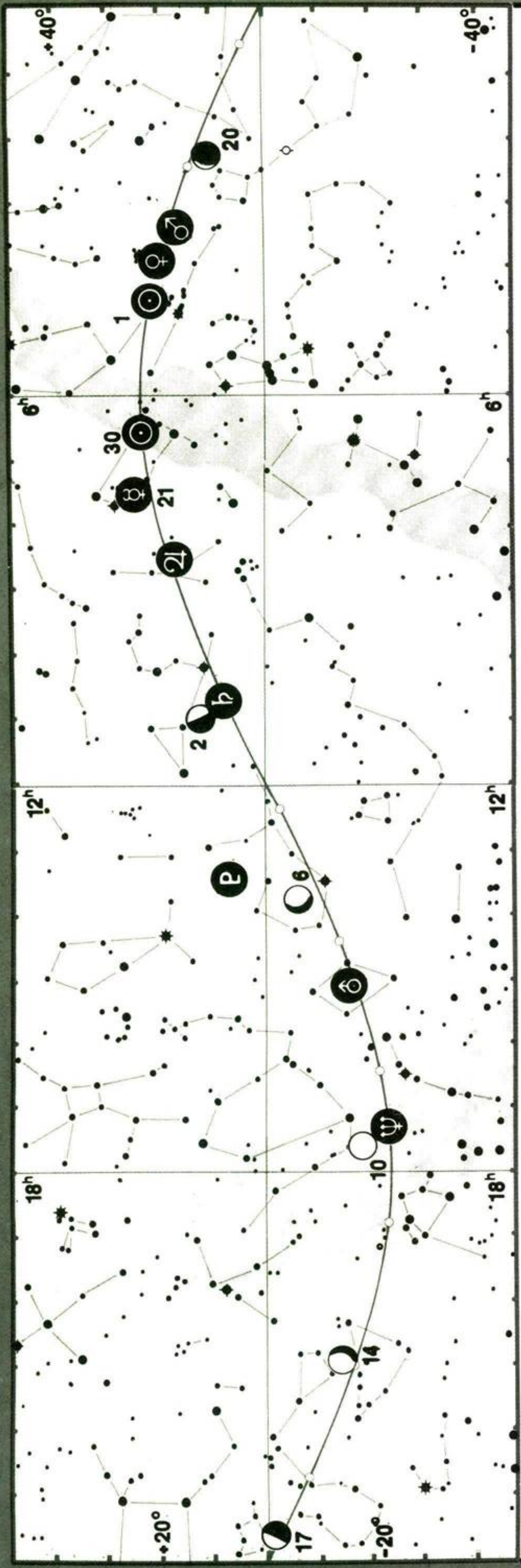
In seeking out these faint satellites, you'll have to find Uranus and sketch the positions of all points of light in its vicinity. Come back again in a day or so and compare your sketch with what you now see. Do this a few times and you'll soon pick out the satellites.

Neptune

During the month of June, Neptune will be an average of 29.25 astronomical units from Earth, or some 2.7 billion miles away. At that distance, the planet's physical size of 33,000 miles' diameter is reduced to an angular extent of barely 2½ seconds of arc. And yet this is on the 10th when Neptune is at opposition, its closest approach to us!

Again, for big telescope owners, there's a dim satellite waiting to be added to your list: Triton, the brighter of Neptune's two moons. (You can forget the other moon, Nereid, which is of magnitude 19 and which orbits with a period of about a year.)

Triton has a retrograde orbit with a period of 5 days 21 hours, is of magnitude 13.5, and physically is about twice the size of our Moon. Triton's maximum angular separation from Neptune comes to about 17" of arc, and it will be at eastern elongation during darkness on June 30th at 8^h35^m UT. Try looking for it at any time during the month if your instrument is big enough, though. As mentioned in connection with Uranus, the basic technique is to map and compare.


+40°
-40°
20
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21
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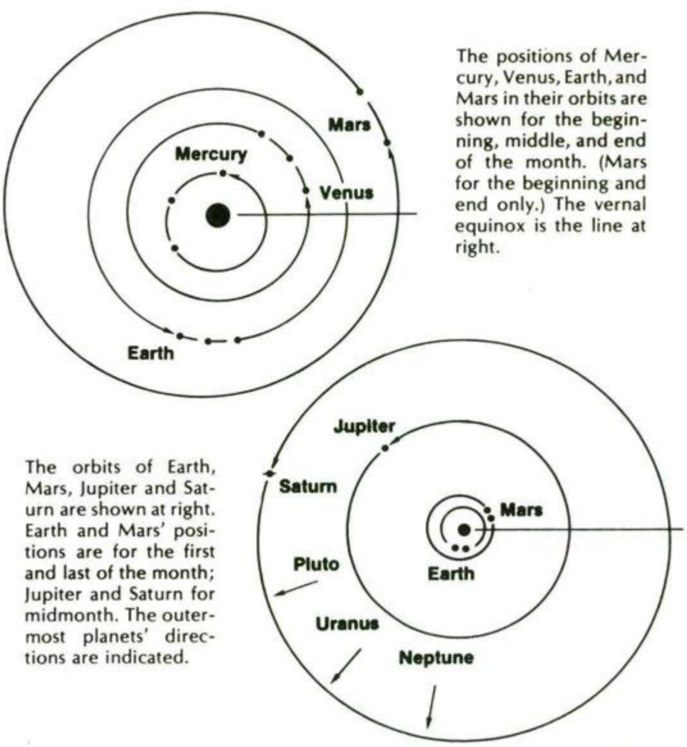
17
-20°

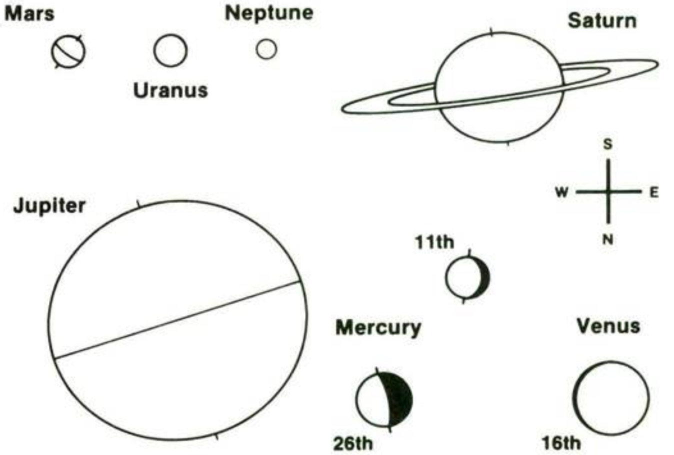
Planet Finder


Mars
Mercury
Venus
Earth
Jupiter
Saturn
Mars
Pluto
Earth
Uranus
Neptune

The positions of Mercury, Venus, Earth, and Mars in their orbits are shown for the beginning, middle, and end of the month. (Mars for the beginning and end only.) The vernal equinox is the line at right.

The orbits of Earth, Mars, Jupiter and Saturn are shown at right. Earth and Mars' positions are for the first and last of the month; Jupiter and Saturn for midmonth. The outermost planets' directions are indicated.

Planet	Date	R.A. (1979.5)	Dec.	Mag.	Dist. (AU)
Mercury ☿	10	$6^h06.4^m$	25°19.3′	-1.0	1.23
	20	$7^h25.1^m$	23°53.3′	0.0	1.07
	30	$8^h22.5^m$	20°09.8′	+0.5	0.90
Venus ♀	10	$3^h43.5^m$	18°32.9′	-3.3	1.58
	30	$5^h26.2^m$	22°47.7′	-3.3	1.65
Mars ♂	15	$3^h18.9^m$	17°53.8′	+1.5	2.20
Jupiter ♃	15	$8^h41.1^m$	18°59.7′	-1.4	6.00
Saturn ♄	15	$10^h42.2^m$	10°14.5′	+1.0	9.57
Uranus ⛢	15	$15^h00.9^m$	-16°45.8′	5.7	17.86
Neptune ♆	15	$17^h12.7^m$	-21°32.2′	7.7	29.27
Pluto ♇	15	$13^h25.9^m$	9°43.0′	14.0	29.85


Mars
Neptune
Saturn
Uranus
S
W
E
N
Jupiter
11th
Mercury
Venus
26th
16th

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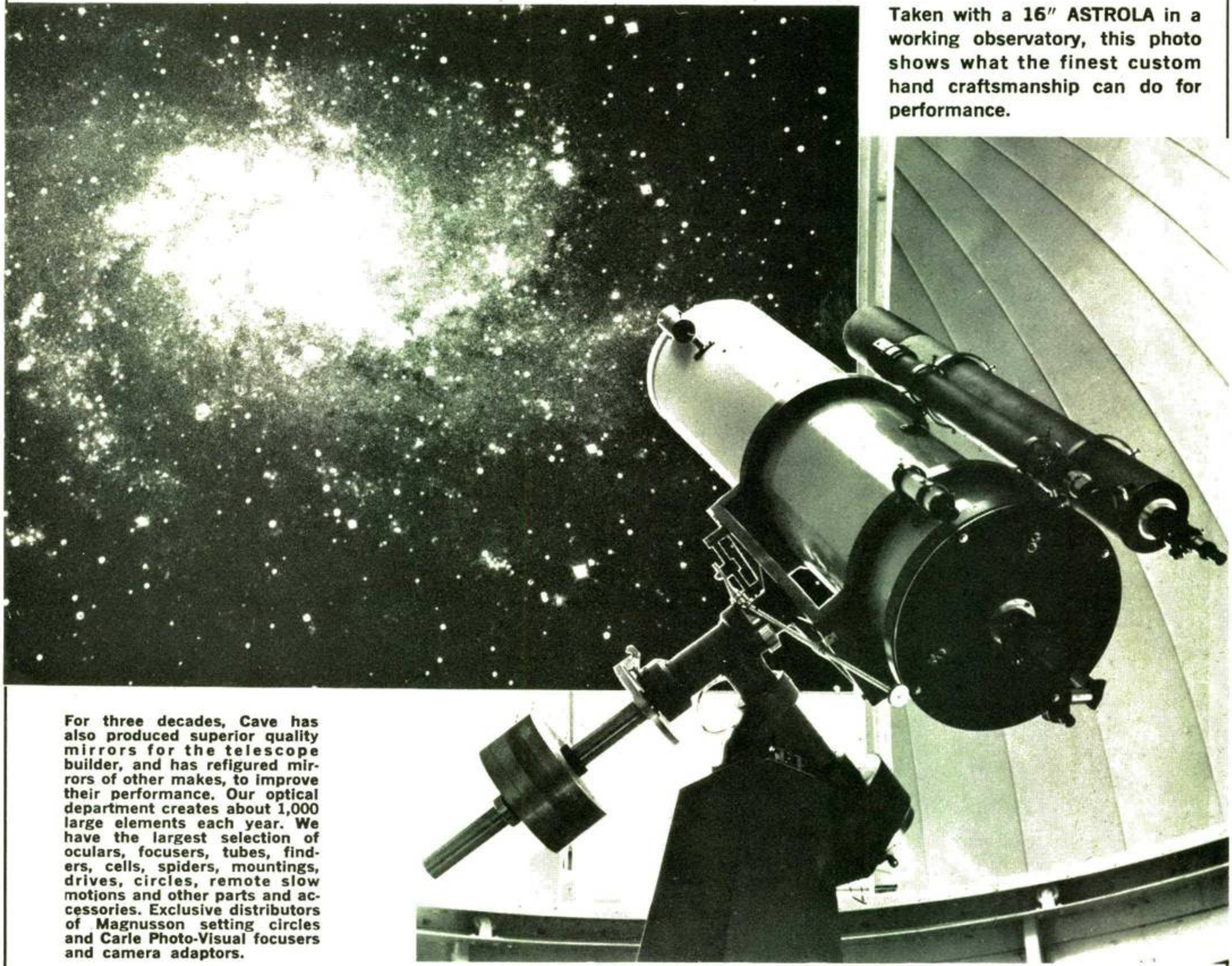

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The Moon:
the Southern Highlands

Spreading south and east from the center of the Moon's visible hemisphere, lies an extraordinary expanse of chaos. Here, craters are piled upon craters in a tortured array of blasted terrain. Looking much like some immense battlefield, there appears to be no level surface at all — just pits, walls, ridges, and hummocks, one after another in a crazy-quilt, aimless pattern.

This is one of the most intriguing of all areas on that very fascinating object — the Moon. The rocks the astronauts brought back from here are chiefly *breccias*, the name given by geologists to rocks made from fragments of other rocks, welded together under tremendous pressure. In fact, many rocks were breccias of breccias of breccias, clearly showing that this place has been pummeled again and again by infalling meteors and planetoids.

Here are found the highest mountains on the Moon, though they lie along the southern limb and are never seen under the grazing light that would reveal their full glory. Here too are traces of the impact that blasted out Mare Imbrium to the northwest — scars carved by boulders flung from the impact site into trajectories that skimmed and gouged the surface for hundreds of miles. The result now lies open for all (with a telescope) to see: the southern highlands.

The main features of this region, of course, are the craters. There are untold billions of them, ranging in size from 225 km-diameter Clavius down to microscopic "zap pits" found on the tiniest of lunar soil particles. While all craters may appear monotonously similar to you, a closer look shows how utterly mistaken this impression is. Go get your telescope and start prowling over this cosmic junkheap — who knows what you'll find.

First, let's cover a few basics (if you've often looked at the Moon, this'll be old hat): 1) Set up your telescope outside on a firm piece of ground. If you have an equatorial mounting, take a few minutes to get it aligned, because you'll find observing much easier if you can follow with one motion. If you're not smack on the pole, it won't matter terribly, since you're just looking; 2) To start with, pick an evening when the Moon's between new and first quarter. Most of the highlands area lies to the east (west in the astronomical sense) of the Moon's central meridian, and so will be lit by grazing light during these phases; and 3) Have a good Moon map available. Later in this article you'll find a short reading list with some suggestions for maps and atlases.

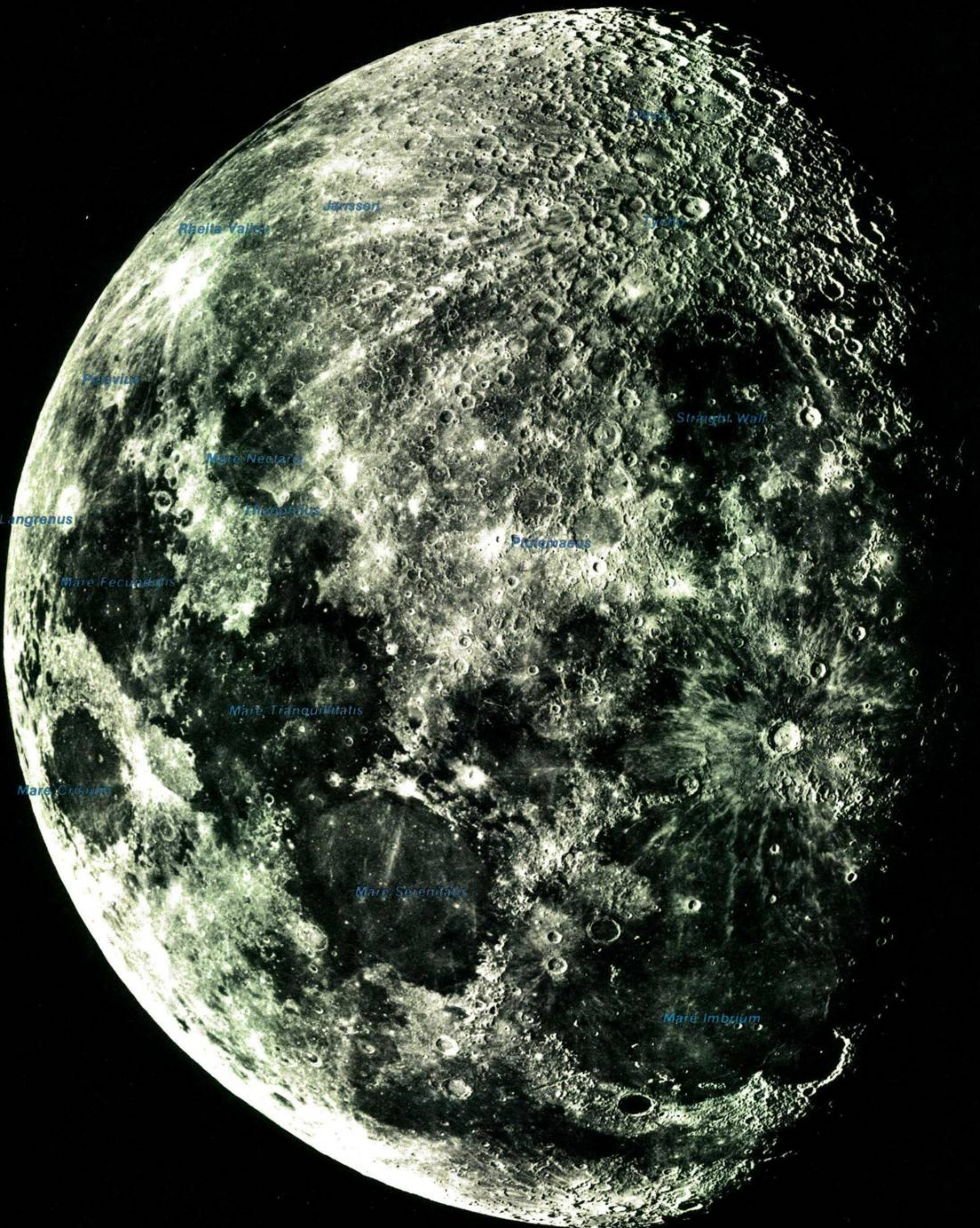
What sort of telescope is best? The best one will be whatever you have. Obviously, if yours has a large aperture, its resolution will be greater than if you were using a small (say, 60 mm) scope. But simple size isn't the deciding factor here. A big scope's main advantage in astronomy is its light-gathering power — something you never worry about with the Moon. What counts most here is the telescope's optical quality.

With a poor telescope, you'll never have fine resolution or be able to crack on those high powers necessary to wring all the details out of an image. Moreover, the unsteadiness of the terrestrial atmosphere will often place severe constraints on the powers you *can* use. Generally, the best you'll ever be able to do is 75x to 100x per inch of aperture, and this only under very exceptional circumstances. A far more realistic figure is about 25x to 40x per inch of aperture.

OK, now suppose the Moon's about 3 to 5 days past new, and you've taken your scope out and set it up. What can you expect to see? Probably the first lunar feature you'll see is a large, oval, dark patch, near the Moon's limb. This is Mare Crisium, one of the smallest of the "circular" maria. (It's about 420 km long in a direction parallel to the limb, and can be used as a rough guide to how big a crater of any given size will appear.)

Along the east and southeast reaches of the Moon's crescent are two craters, approximately equal in size: Langrenus and Petavius. Langrenus, the more northerly of the two, is about 130 km in diameter and has steep, terraced walls descending almost 2.5 km to a relatively level floor. At the center of the floor is a group of peaks consisting of several individual bumps, the highest of which is about a kilometer above the crater floor. Look for some lower hummocks on the floor, and for

The Moon's broken and tumbled southern highlands lie in the upper center of the disk. Various features have been named in this photo taken when the Moon was 10 days old. As with the rest of the photos in this article, south is at the top, corresponding to the view in a telescope. Lick Observatory photo.


Clavius
Janssen
Rheita Valley
Tycho
Petavius
Straight Wall
Mare Nectaris
Theophilus
Langrenus
Ptolemaeus
Mare Fecunditatis
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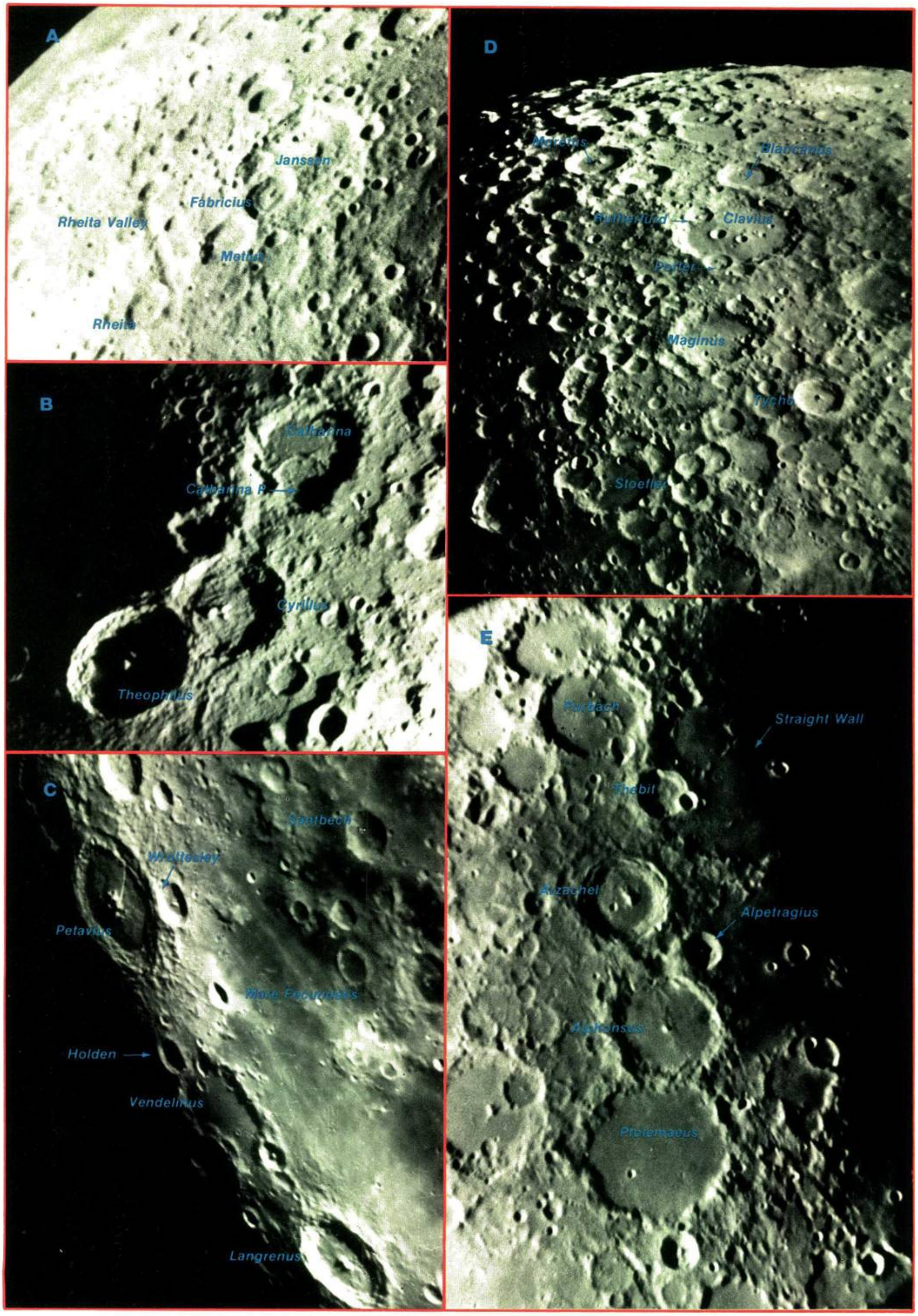
Mare Crisium
Mare Serenitatis
Mare Imbrium


A
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Petavius
Mare Fecunditatis
Holden
Vendelinus
Langrenus
D
Moretus
Blancanus
Rutherfurd
Clavius
Porter
Maginus
Tycho
Stoefler
E
Purbach
Straight Wall
Thebit
Arzachel
Alpetragius
Alphonsus
Ptolemaeus

Photograph A: The Janssen and Rheita Valley region was photographed on Plus-X using a 1 second exposure through a Schmidt-Cassegrain with Barlow lens. Photo by Jean Dragesco. **B:** Theophilus and its companions under sunset lighting, taken by Jean Dragesco with a 42" f/12 telescope on Pan-F with a 2 second exposure. **C:** Petavius is the crater at the top, Langrenus at the bottom. Photo by Jean Dragesco using a 10" f/20 telescope on FP-4, 2 second exposure. **D:** The rough terrain from Tycho to the south pole shows up well here under late afternoon light. Photo by Ken Owen with his 10" f/6 Newtonian. The film was XB-14; the exposure was 6 seconds. **E:** Alphonsus and environs in the early morning light near first quarter. Tim Tomljanovich used a 6" scope with eyepiece projection onto Tri-X for ¼ second.

terraces on the inside, which will be slumped wall materials.

Petavius, farther to the south, is slightly bigger: 160 km in diameter. While it's bigger than Langrenus, Petavius can be harder to spot because its contours are less pronounced. This crater, too, has terraced walls and an expanse of floor punctuated by a central mountain complex, but the walls vary in height from 2 km (in the east) to over 3.5 km (in the west, where the wall is of double thickness). The central peaks are about 1700 meters high. Extending from the central peaks toward the walls on the west-southwest is a *rille*, a name given to any lunar gully. This rille is very easy to spot, and some observers have thought it has a slightly raised lip.

The smaller crater adjoining Petavius' western wall is Wrottesley (57 km diameter), which looks like a miniature version of the larger crater, except for the unterraced walls.

The details in Petavius are often best seen under lunar "evening" light, that is, when the Moon is about a day or so past full.

Farther still to the south along the limb region lies the Rheita Valley. Near the large ruined crater Janssen, this Valley is a chain of interconnected craters and depressions extending for about 180 km to the southeast from the crater Rheita. Rheita is 70 km in size and has a relatively smooth floor with a small central peak. Terracing is slight, and there's a craterlet on the inside of the north wall.

The Valley itself is about 20 km wide and rather shallow, though the floor is very uneven. The northern side appears to be slightly deeper then the southern, but this may be a lighting effect. The origin of the Valley is probably volcanic.

Janssen is a large, ruined, old crater with its outline much battered by adjoining features. It is 190 km across, and the floor is littered with hills and hummocks, though it lacks a central peak assemblage. Extending to the south from the large crater in the northern wall is a long rille. The large crater in the wall is Fabricius, some 78 km across and 2.5 km deep. It has a central peak array and terraced walls suggesting extensive slumping.

About half way between new and first quarter, the lunar cycle brings into prominence a group of three craters on the southwest shore of Mare Nectaris: Theophilus, Cyrillus, and Catharina. The first of these is the most well-preserved, and displays a truly amazing variety of shapes and features both inside and just outside the walls. It's about 100 km in diameter, and has walls that rise 1.2 km over the surrounding landscape, then plunge almost 4.5 km to the floor. Part way down the northwest wall, on the inside, lies a small (9 km) crater, Theophilus B.

The central mountain group rises some 2000 meters above the floor, and is made up of many separate peaks and blocks. The wall appears to have thickened and is more rubbly on the part that's next to Cyrillus. From the appearance, it's clear that Cyrillus was formed first, with the arrival of Theophilus intruding on, and partially filling, Cyrillus.

The partially disintegrated wall of Cyrillus spans a diameter of about 95 km, making it almost the same size as Theophilus. Inside, though, they differ a good deal. Cyrillus has almost no smooth floor, and the central peaks are accompanied by many low humps scattered all over the floor. The central mountains here divide into three basic peaks with numerous lower ridges. The crater in the southwest part of the floor is Cyrillus A, a smooth cuplike formation about 15 km across.

Catharina, the third member of the trio, lies slightly apart and to the south of Cyrillus. As if continuing the age-trend, Catharina seems to be old and battered down. The shape of the rim walls is rather irregular, though the average diameter is about the same as the aforementioned other two — 90 km. The floor has no central mountains, but is littered with broken hills and ridges. The northern half of the floor is taken up with the remains of an old ruined crater, Catharina P, which appears little more than an irregular depression. The wall of Catharina P is very low where it borders on the rest of the crater floor.

Skipping ahead to a time near first quarter, you'll glimpse one of the most fascinating events you'll ever see on the Moon: sunrise over Ptolemaeus. This very large (153 km) but shallow (2.4 km) crater has a floor that appears essentially flat under most lighting. But when the sunlight is coming in at a very low angle, every little hump and dip stands out in bold clarity, revealing a surface that has a thousand little details. The scientific opinion is that Ptolemaeus was formed as a deep, "normal" crater and then was filled with lava. When the lava flowed out over the existing floor, it inundated and melted the structures there, softening their contours. The "paleotopography" now can be seen only when the sunlight is grazing: that is, at sunrise or sunset.

The single distinct crater on the floor is Ptolemaeus A, a 9½ km bowl. Just to the north of A lies the larger but ruined and very subdued crater Ptolemaeus B, though little remains of it but a low rampart. You'll need grazing light to make it out.

Adjoining Ptolemaeus to the south is Alphonsus, a 118 km diameter crater which caused quite a stir among professional lunar scientists about 20 years ago. One night in 1958, the Soviet astronomer Kosyrev noted that the central peak of Alphonsus was abnormally bright. As he watched, the peak got brighter and began to turn reddish. Working quickly, he managed to get a spectrographic plate of the phenomenon, though by the time the exposure was over, the brightening was almost totally gone. The resulting spectrograms have been discussed and disputed almost endlessly, but it seems likely that what he saw was a real event, if somewhat uncertain in cause. Before and since, similar events have been noted by observers, chiefly non-professionals, and the phenomena have been given the name of LTPs, or lunar transient phenomena.

No one knows just what produces them, and some percentage is likely caused by eager observers straining to see something they want to see. It is clear, however, that there's no particular reason why the Moon couldn't be outgassing stuff from time to time, stuff which might on exposure to the surface generate a sudden LTP.

Alphonsus' floor has a number of darker patches on it, which are now assumed to be outcrops of volcanic lava, and there are a number of tiny, "dark-haloed" craters which are thought to be volcanic vents. Unfortunately, these are hard to see because they're small. Ranger 9, which crash-landed here in March 1965 gave us our first close-up views of the crater via live television.

Just to the southwest of Alphonsus lies the curious crater Alpetragius, a medium-to-small sized (40 km) crater, the inside of which is almost filled by its central peak. Someone once described it as the "egg in a basket" and you can't help agreeing when you see it. There actually is a bit of floor in there, but not much. The peak rises 1800 meters over the floor, which lies 4 km below the rim.

Due south and a little west from Alpetragius is a curious feature known

Lunar Maps, Atlases, and Books

You can always find your way around the Moon by learning a few of the more recognizable landmarks, but to feel truly "at home" there, some supplementary guides are in order.

Maps

One of the best was put out by the National Geographic Society in 1969: **The Earth's Moon**. It shows both nearside and farside hemispheres, and is drawn on an "equal area" projection. You can write the Society for current prices or try a second-hand book store for a copy.

Rand McNally has a series of wall-sized lunar charts which show the nearside hemisphere in an orthographic projection. This means that features next to the limb are foreshortened the way you see them in reality. The maps are a skillfully-matched mosaic of photographs.

Atlases

There are three lunar atlases generally available: the (London) **Times Atlas of the Moon**, the **Atlas and Gazetteer of the Near Side of the Moon**, and the **New Photographic Atlas of the Moon**. The first of these is a reprinting of the 1:1,000,000 scale lunar maps prepared by the ACIC branch of the U.S. Air Force. They show all details reliably seen with medium-size professional telescopes.

The second atlas was prepared by NASA and consists of photographs taken by Lunar Orbiter IV. Since the photography was done from lunar orbit, the images are very clear and show lots of details invisible from Earth.

The third atlas (by Zdenek Kopal) is also photographic, but the shots were taken from Earth-based observatories. There's an extensive introduction about the Moon and lunar studies, as well.

Guidebooks

There have been many lunar guidebooks with sectional maps in them coupled with a matching description, but most of them are out-of-print, if not also out-of-date.

A handy, pocket-sized book is **Moon, Mars and Venus**, by Antonin Rukl. It has a map of the Moon in 76 sections with a short description of features on the facing page. (It's available from ASTRONOMY.)

Patrick Moore is the author of a **New Guide to the Moon**, which mainly surveys current (1976) knowledge of the Moon but also includes a 16 section map and description of the surface features.

Some years ago, Moore collaborated with Percy Wilkins on **The Moon** (Faber and Faber, 1959), which had a 25 section map and exhaustive description. The maps are hard to use, due largely to their cartographic conventions, but the descriptions are good. The book is now out-of-print, but second-hand stores and libraries often have it.

The best lunar guidebook of the 19th century is Edmund Neison's **The Moon** (Longman's, 1876). His map is in 22 sections and the descriptions are generally excellent. Some of his place names are no longer used, but by checking his map with a current one, you won't go wrong. (Neison's book is available in second-hand shops, but rather costly and unfortunately most libraries won't let you take their copy home — which is a shame. Maybe you'll get lucky and find a copy to own.)

as the Straight Wall. This fracture in the surface of the mare isn't really a part of the highlands, but it's worth noting here anyway. Originally, the Wall was thought to be a nearly vertical cliff, and some rather imaginative drawings were done showing a "typical" vista near it. However, continued research has reduced the slope to about 30° to 45°. When you see it at local sunrise, the Wall, of course, is in shadow and appears dark. Disappearing for the most part around full phase, the Wall brightens through the long lunar afternoon, standing out clearly again at sunset.

Continue your way southward and you soon arrive at two of the most splendid and distinctive craters on the Moon: Tycho and Clavius. Tycho is the center of the Moon's largest ray system, and is a yawning pit 80 km across and 3.5 km deep. The central peaks rise to about 1500 meters above the depressed floor. The walls show terraces, indicating that some slumping has happened since its formation.

The ray system only stands out really well at the time of full phase, when it becomes truly spectacular. One theorist proposed some time ago that the Moon must be made of a glassy substance, since the ray system made it look like a glass sphere that had been struck with a blow sufficient to send cracks partway around the surface. This idea no longer gets much consideration, needless to say, but it does convey something of the visual impression. Also curious to note is the way the rays lie not exactly radial to the crater, but rather more as tangents going out from the edges of the rim. Moreover, Tycho is surrounded by a dark ring to a distance from the rim of about one crater diameter.

South and a little west of Tycho lies the great crater Clavius, 225 km across and 5 km deep. Clavius has no apparent central peak array, but does have numerous craterlets within it, and two more substantial ones on the northeast and southeast rims, respectively. The southern is named Rutherfurd, the northern one Porter. Both are about 50 km in size, and have interior structure (central mountains, hummocks, etc.) worth examining.

If you look at the craterlets on the floor of Clavius, you'll notice that starting with the littlest one in the west, they curve around in a nice arc, increasing in size gradually and smoothly, until they end up at Rutherfurd. Much has been made of this by those who foster the volcanic theory for crater origins, but no one really knows if it's coincidental or real.

Now shift your gaze to the southern limb of the Moon's disk. Here, silhouetted against the black of space are the tallest mountains on the face of the Moon. Because they're so far away and surrounded by highly jumbled terrain, they may not appear as impressive to you as the lunar Apennines do, lording it over Mare Imbrium. But these mountains have peaks that soar as high as 10 km, well over Everest's height.

We can't do more here than point out just a couple of the more striking objects to be seen in this tangled, littered region, but there are many, many more features, all worthy of your gaze. The more you look, the more you'll see, until you can only marvel that scientists dare hope to piece together the story of how this wilderness ended up as we see it now.

— *Robert Burnham*

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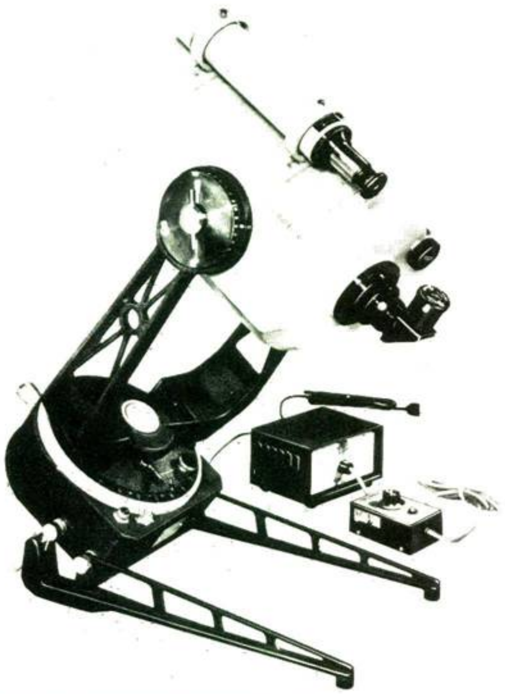

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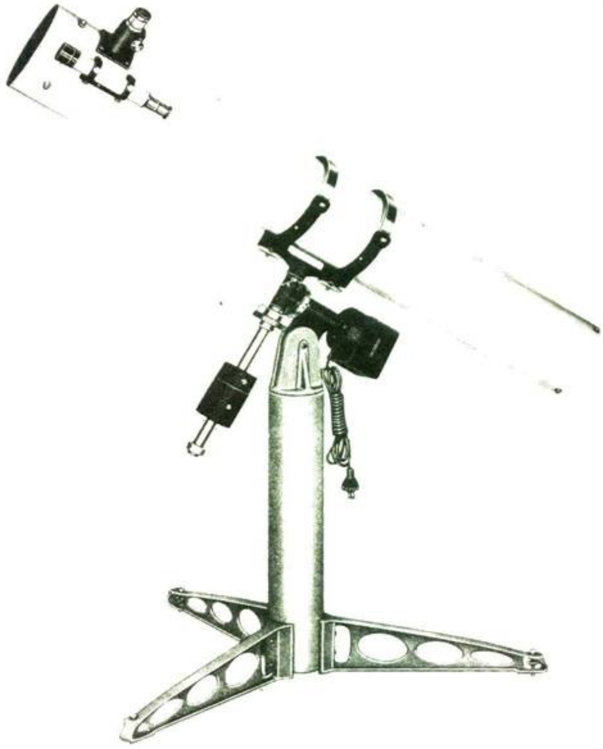

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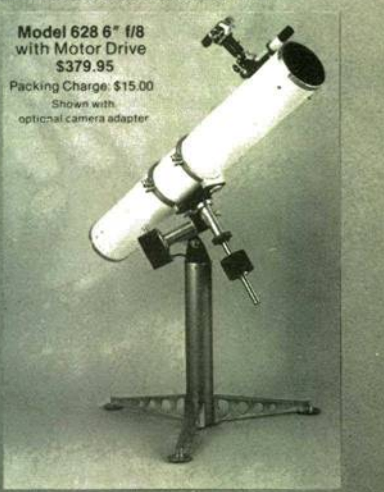

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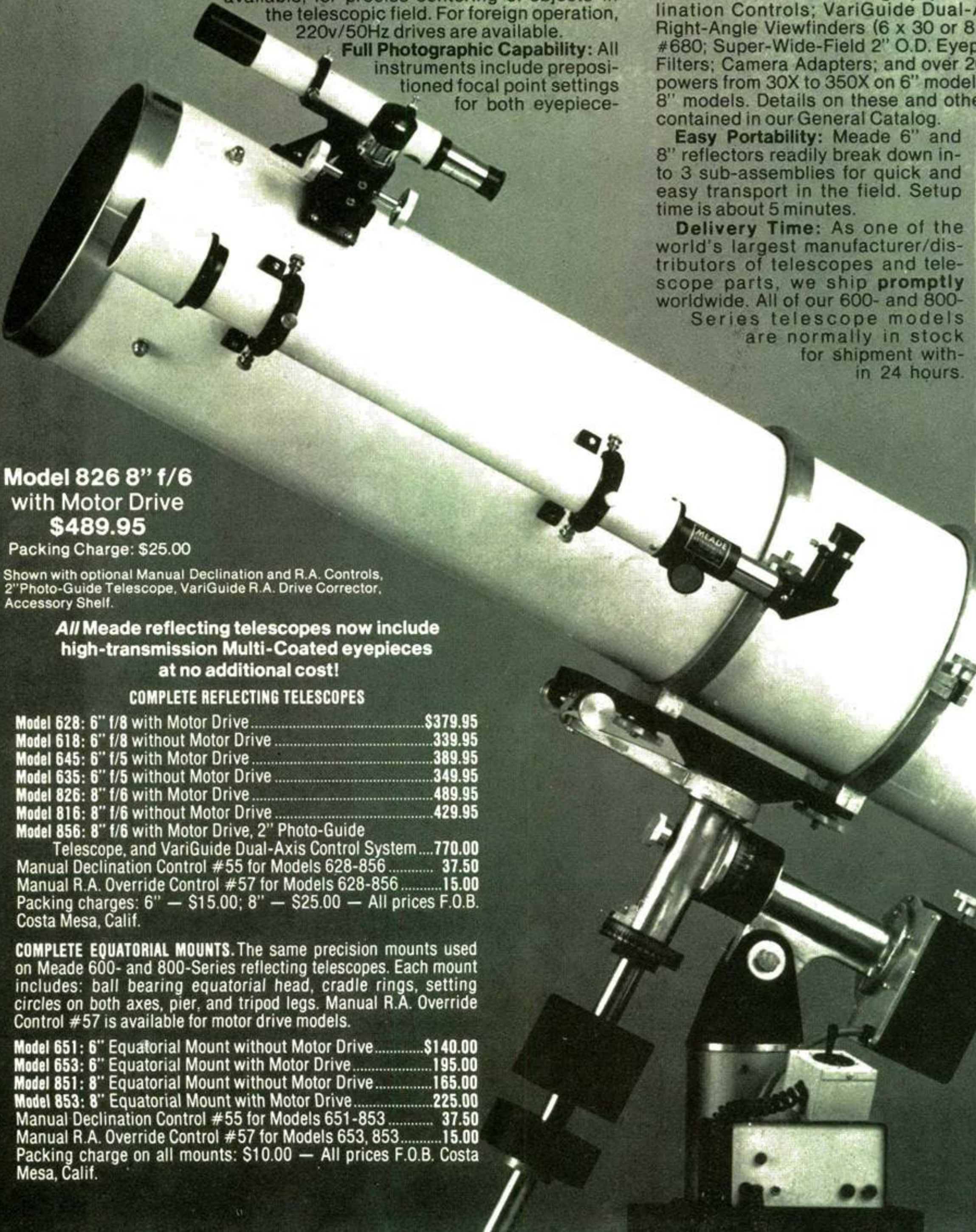

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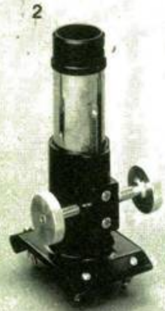

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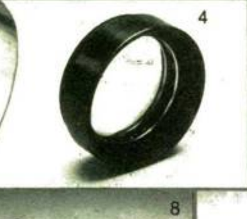

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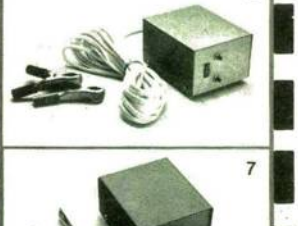

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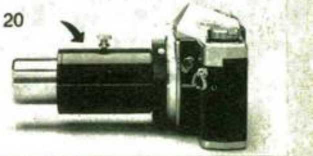

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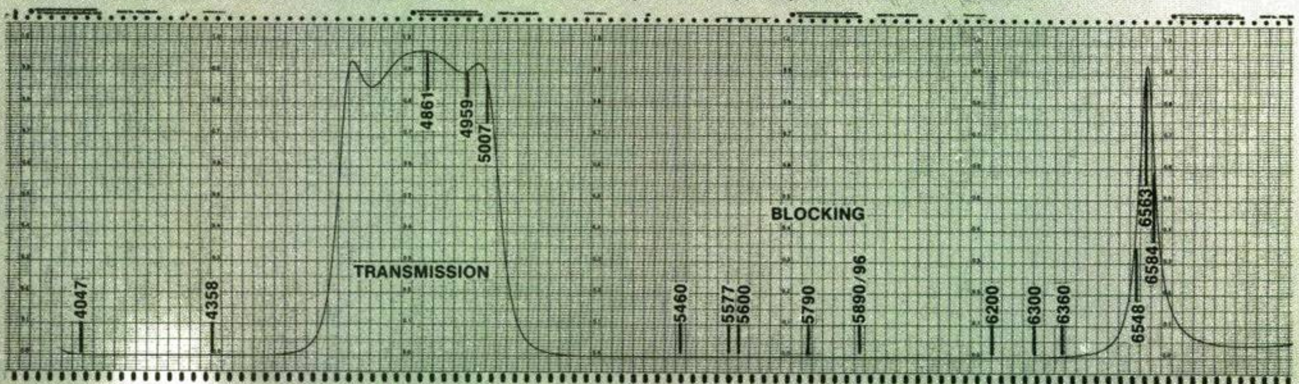

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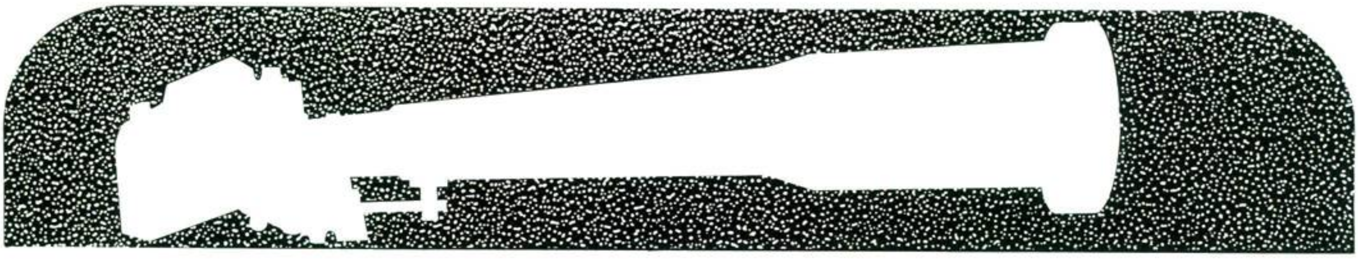


Ektachrome 400:

Answer to the Astrophotographers Dreams?

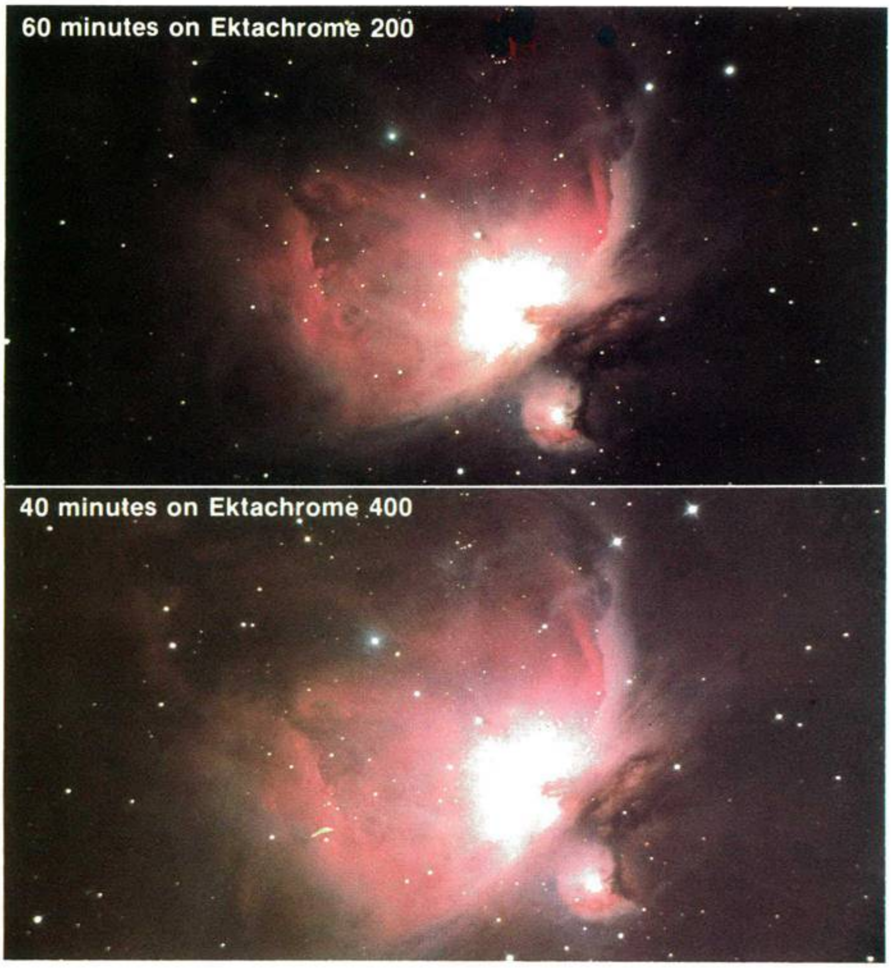
What would be the *ideal* film for deep-sky astrophotographers? What characteristics would satisfy the demands of this particularly picky breed?

First, the ideal film would have to be fast. How fast? Using the spectroscopic emulsions now offered as standard (remember that these emulsions approach the theoretical limits possible for a chemically-based, one-shot image recording medium), the ideal film would have to be nearly as fast as the spectroscopic emulsions.

Second, it should be a fine-grained film. It doesn't have to be utterly grainless, but it should stand up well to a 10x enlargement. That's more enlargement than you'd normally expect with the spectroscopic emulsions, and for most telescopes, it's consistent with other sources of image fuzziness, namely atmospheric turbulence, guiding errors, and optical aberrations.

Third, it should be a color film. Spectroscopic films are black and white — and they are a complex, highly quality-controlled product. It's tricky and time consuming to make a color image from three color-filtered black and white — even though the results are superb — but it's very easy to convert an original color transparency into a good black and white print. Therefore, if you're specifying an ideal film, you might as well make it a color film.

And fourth, the ideal film should have little reciprocity failure. Reciprocity failure is the bane of astrophotographers everywhere — and it comes from the inability of film to efficiently store up a very faint image during a long exposure. It means that if a starry sky is one ten-millionth as bright as an ordinary daytime scene, the length of exposure needed to record the starry sky is more



In a 40-minute exposure, Ektachrome 400 shows fainter stars, more nebulosity, and better retention of stars embedded in bright nebulosity than Ektachrome 200 does in a 60-minute exposure. John P. Gleason took these comparison photographs using a cold-camera attached to a Celestron 8. Overleaf: An enlargement of the Ektachrome 400 frame shows acceptable graininess, good color retention, and dramatic impact in rendering the Orion Nebula, M-42.

— much more — than ten million times as long. Now reciprocity failure is a good thing: without it, you couldn't store film. The tiniest glimmer creeping through a filmbox would add up and up to wipe out and fog your film. Reciprocity failure means the emulsion ignores that tiny glimmer, and stays fresh (and unexposed) when low levels of light strike it.

Perhaps, then, we'd be willing to make a compromise. Anyone who's worked with spectroscopic films knows how troublesome it is to store them in a freezer, etc., etc. But if we're going to tolerate reciprocity failure, let's ask that it be easy to "turn off."

Ekta 400: It's Here!

Is Ektachrome 400 the wonder film that we've been talking about? The answer may be a qualified "maybe" — Ektachrome 400 does indeed appear to be the best yet. It's rated 400 ASA and it actually is that fast (fast films aren't always the speed they're claimed to be). Not only that, but it pushes well to 800 ASA and even acceptably (though grainer and with some quality loss) to 1600 ASA. It's not a grainy film, though obviously more so than the 25 ASA fine-grain quality champs. It's a color film, and even does well on such non-astronomical subjects as "Aunt Martha and the kids at the beach."

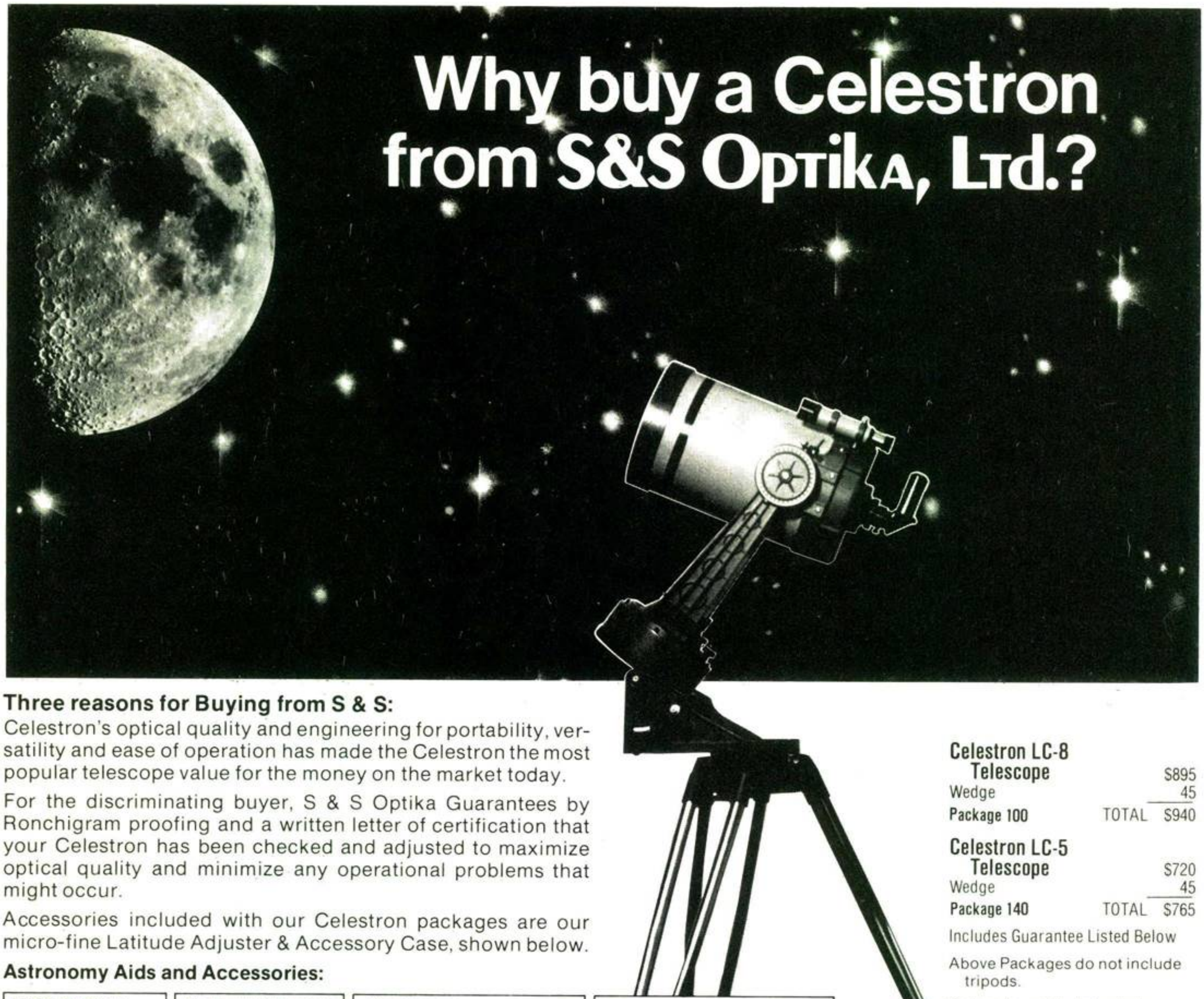
And what about reciprocity failure — is it good at that? Well, it *has* reciprocity failure, and at normal temperatures it's about like Tri-X: good for exposures under ten minutes or so. It's good for Milky Way pictures with a fast lens, and, like Tri-X, is still collecting an image at the end of an hour-long exposure, albeit slowly.

But the failure has an "off switch." Cool Ektachrome 400 to forty below (Fahrenheit and Celsius are the same at -40°, remember?) and it sheds the reciprocity failure. In a cold-camera (a fuss and a pain and a bother to use — dry ice, frosted fingers, brittle film), it's nearly the ideal deep-sky film. Its color balance is good, image contrast is acceptably high, colors are believable, and grain and sharpness fall well within acceptable bounds.

Obviously, no film will do miracles for a sky with light pollution, an exposure poorly guided, or an image out of focus. But Ektachrome 400 does an excellent job — better than any of its Kodak predecessors — and it approaches the characteristics of an ideal film for deep-sky astrophotography.

Near the Orion Nebula is another beautiful region of nebulosity known as M-43. The same technique — Ektachrome 400 in a cold camera — was used in this 40-minute exposure with a Celestron 8 telescope. Photograph by John P. Gleason.

Why buy a Celestron from S&S Optika, Ltd.?



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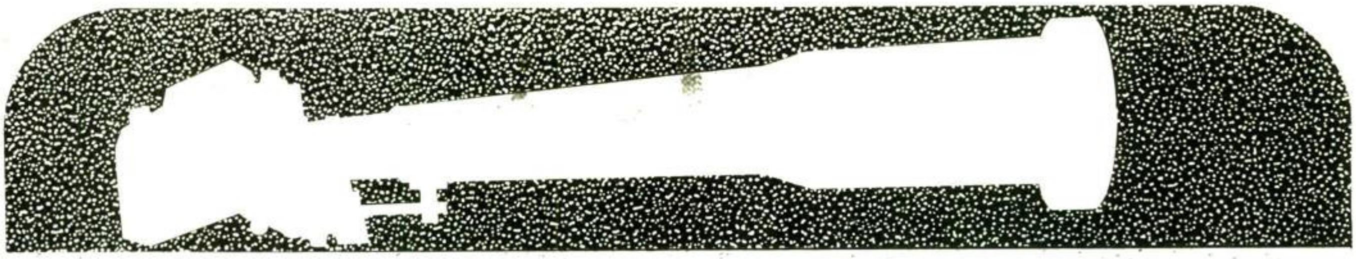


PHOTOGRAPHY IN ASTRONOMY

How to Photograph a Space Ship

by
Paul Maley

When the space race was on and American interest in exploring the vastness of space was at its height, it wasn't uncommon to see groups of vigilant observers, field glasses in hand, scouring the night skies. Now, years later and after a long hiatus, some vivid and imaginative "space" movies may have renewed part of that interest.

But while **Close Encounters** may serve only to inspire another great upswing in the ever-recurring UFO nuttiness, many people seem to have forgotten the *real* space ships in the sky — satellites of terrestrial manufacture. These are the space probes of the United States, Soviet Union, Canada, India, Japan, and others that dart into view on most clear evenings. Many members of this fascinating family can provide an exciting challenge to the watchful photo enthusiast.

Now that 35 mm single lens reflex (SLR) cameras are so readily available, the ultimate recording device is in the hands of almost every curious soul. Remember a year and a half ago when the re-entry of the nuclear-powered Soviet surveillance spacecraft Cosmos 954 happened over northern Canada? Had you been there, camera in hand, you'd have caught a blazing fireball as it seared across the night sky: a spectacle well worth capturing on film. (Unfortunately, I was caught without a camera in 1967 when Cosmos 166 made a similar dramatic re-entry.)

But the best "target of opportunity" for the astrophotographer is America's derelict space station, Skylab. This 80-ton laboratory once housed human photographers who snapped countless pictures of us here on Earth. Now abandoned but not forgotten, Skylab glides around the planet in a decaying orbit, getting steadily lower.

If you've ever had a hankering to see the craft, do it soon. Now is your last chance to photograph it before re-entry. NASA doesn't know the exact date, but it'll come down this month or next, perhaps as late as August. Skylab is very bright, making it easy to spot, so don't pass up the chance.

A simple rig using a 35 mm SLR with fast lens (f/2 or better) and fast film (Tri-X or Ektachrome 400) mounted on a sturdy tripod will produce excellent results. In fact, any satellite that's as bright, say, as the North Star can be recorded by following a few simple guidelines. The photography is absurdly simple: it can be done without highly specialized or expensive gadgets, and is certainly not confined to the sophisticated professional.

Satellites are not luminous in themselves so they shine only by reflected sunlight. Due to the changing phase angle between you, the satellite, and the Sun, the spacecraft will tend to vary in brightness. In the case of Skylab and the forthcoming Space Shuttles, their low orbits and consequent high velocities mean you'll have to be on your toes to catch them as they speed across the black backdrop of night, despite their brightness.

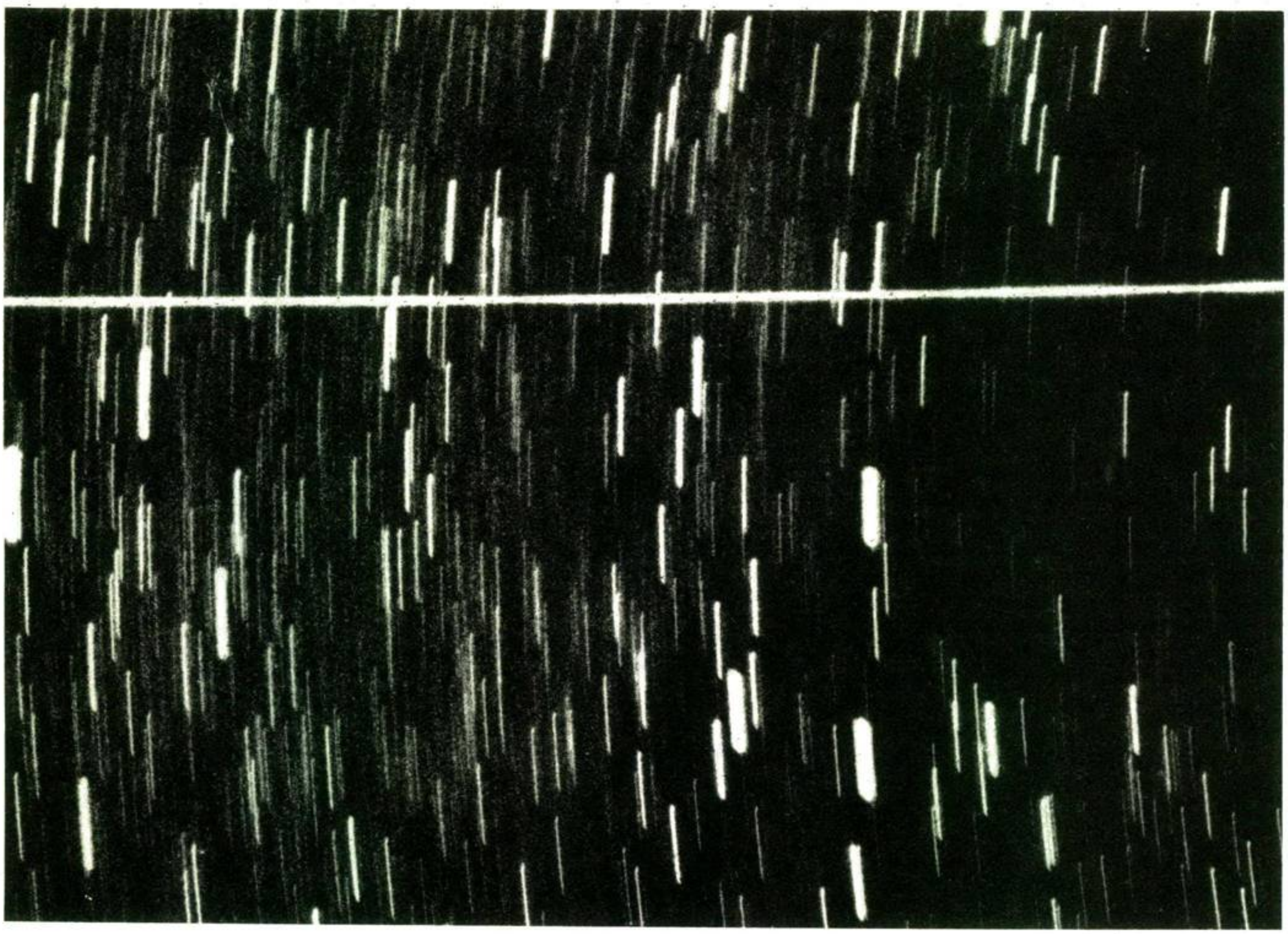
For you urbanites, the best advice is to stay away from lighted areas. This may seem difficult or impossible, but it really is an important requirement. Finding the darkest spot you can will nearly always get you a good photo.

On occasion, a spacecraft will be attended by others, so on a single frame you could capture an orbiting duo such as the Soviet Salyut 6 space station and its latest Soyuz crew. For the bright satellites, NASA has an office that'll provide visibility predictions: see the box on page 52.

All right then, when is the optimum time to photograph? Low orbiting spacecraft are best seen 40 to 90 minutes after sunset or prior to sunrise, against a cloudless sky free of moonlight. The time period when the satellite is in full sunlight but you are in darkness is when it'll stand out most strongly.

The best locations will be dark sites in the suburbs or country where the sky isn't glowing from city lights. The more rural the area, the better your results. You also get a low horizon in the country, too.

How do you go about finding the object? The best method for spotting a satellite is to adhere to the viewing



direction and time as published in NASA's predictions. A successful photo is the result of careful eyeball observing and quick reactions during the short visibility period you'll get.

The spacecraft will appear as a star-like object moving at uniform speed on a moderately curved path. The most common directions of motion are southwest to northeast or northwest to southeast. Because the craft is speeding along at thousands of miles per hour, you'll usually have just 3 or 4 minutes in which to find it and take the photograph.

But don't be fooled by airplanes! These are commonly mistaken for satellites at night, especially when they're distant. It's a good idea to carry a pair of binoculars with you to examine any moving light for the tell-tale flashing of a strobe beacon or landing lights. The angular velocity of Skylab across your field of view, for example, approximates that of the average airplane.

The most clear-cut method of identification is checking the time and directional data in the prediction. Having a well-calibrated watch to consult is a real help also.

Some precautions: Be sure your space shot is not the first photo on the roll of film. Quite often automatic photo processing labs use the first frame as a guide for slide mounting. A dark photo such as this tends to blend with the background emulsion and can easily cause confusion on the part of anyone who processes your film. So take a "calibration" photo at the start of the roll: a tree, a house, or whatever, so long as it has clearly defined edges to the frame.

When you set up the shot, make sure the camera tripod is sufficiently anchored so that all legs are stable and on firm ground. Some people put a weight in a bag and hang it between the tripod legs to add stability. Use a locking cable release to minimize shaking.

If your camera has a "B" setting on its exposure dial, use this in preference to the "T" mark. The reason is that on some cameras the T setting requires moving the winding lever to close off the exposure. Touching the body of the camera is asking for a jiggled photo. (Have a Polaroid? Some models have the B setting feature, and with the use of ASA 3000 black and white film, you can record as well as with an SLR.)

You should be out, in position, and set up several minutes before the predicted arrival time for the satellite's transit. Adjust and aim your camera in the approximate direction where the satellite will reach its maximum elevation above the horizon.

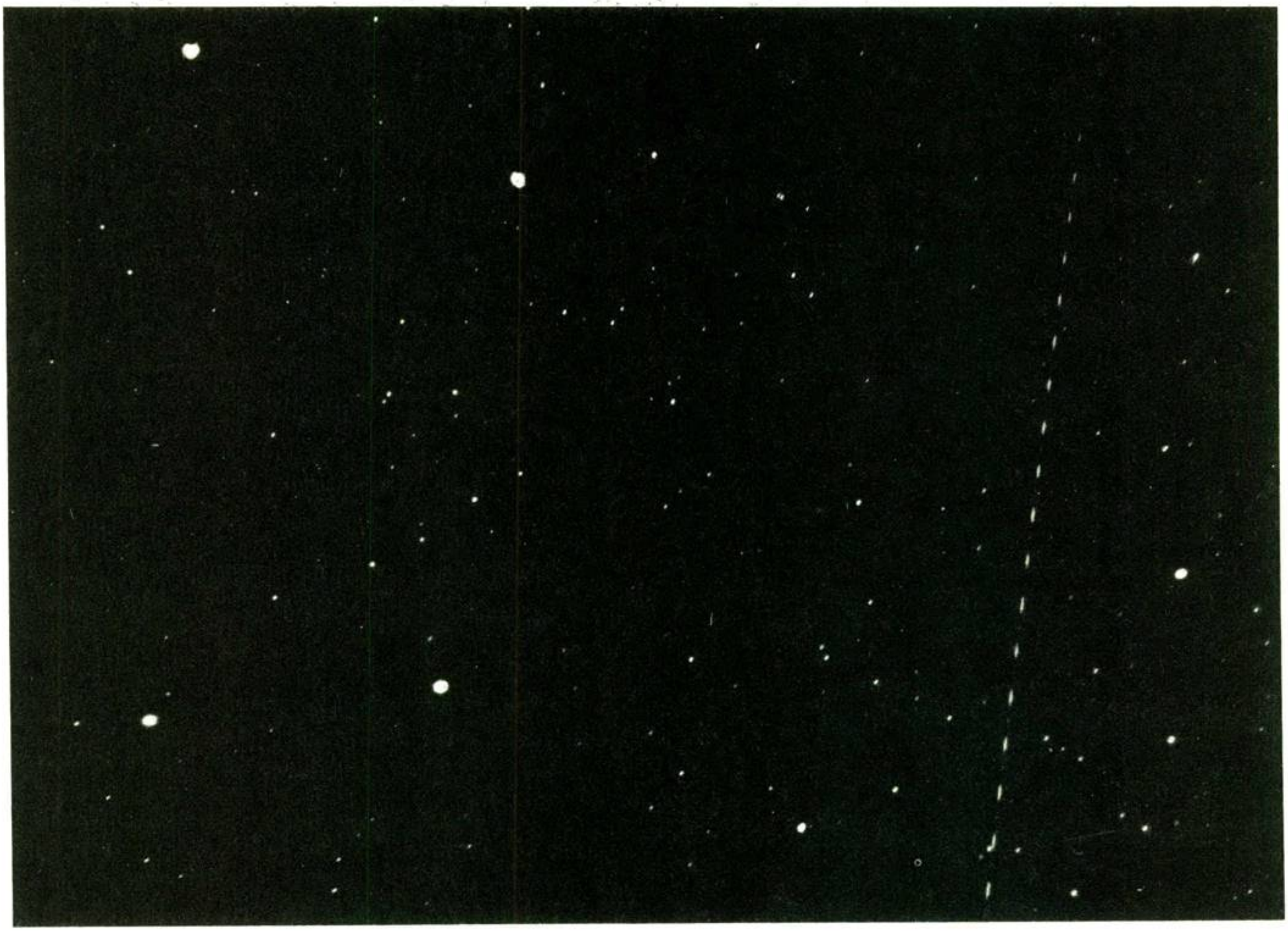
Satellite Pageos A was 2920 miles above the camera when this 3 minute exposure was made on August 19, 1966 from Canyon Lake, Texas. The satellite was on a south-to-north track. Photo by the author.

Set the lens at the widest aperture (lowest f number) and turn the focus to "infinity." On some cameras' focusing scales, you see a person, a group of people, and mountains. In this case, use the "mountains" setting. With an SLR, test to see if the focus is correct by looking through the viewfinder at a bright star and adjust the lens to get a pinpoint stellar image.

If you don't do this, you'll likely get stars recording as fuzzy, dim blobs, and the spacecraft might not show up at all. Framing the view to add the recognizable silhouette of a tree, building, or other structure will give a more complete picture.

Once you spot the satellite, look through the viewfinder and aim the camera so the satellite path will intercept your field of view. You'll have to move the camera by hand to "lead" the object sufficiently. Then lock the camera in place, and let the spacecraft approach the field. Open the shutter just before it enters, as this will minimize vibration.

Expose for about 30 seconds. This



Above: The rocket body of Cosmos 116 left an interrupted track as it tumbled in orbit. To the left are the four stars making up the bowl of the Big Dipper. The exposure was 22 seconds long. Photo by the author. Right: A five minute shot looking north caught an unidentified satellite as it crossed through the Ursa Major region. ASA 100 slide film was used with a 55 mm lens at f/2. Photo by William Hodgson.

will be optimum for recording twinkly stars that look like stars instead of lines. Since the Earth, the camera, and you are rotating while the photo is being snapped, opening the shutter too long has two adverse effects: first, the stars will tend to trail on the film, producing elongated streaks rather than points; and second, the proximity to dawn, dusk, or nearby lights may cause the film to fog.

After the satellite has passed through the field, place a piece of black cardboard completely over the lens but not touching it. Then unlock the cable release. This shuts off the exposure without visible wiggles.

If you don't do your own processing, get it done by a quality outfit. Inexpensive labs often use old and worn-out chemicals, and leave residue and scratches on the film. Normal processing developers and tank times can be used, but if you can, ask for extra contrast. Black and white prints should be done on high contrast paper.

Predictions

Readers who'd like localized predictions of where to look for Skylab's passages should write to:

William O'Donnell
Code LFD6
NASA Headquarters
Washington, D.C. 20546

What can you expect to see? The path of a satellite like Skylab as it slides across the stars will be a line that transits the frame from side to side or end to end. If the orbiting ship is tumbling or rotating, the line of its path may show a bright and faint cyclic pattern. This will usually be visible to the eye as well, and you can time it with a stopwatch.

Be careful that you don't take a scratch mark on the film for the satellite trail. (The scratch will usually run beyond the edges of the frame.) And to sort out any accidentally recorded airplanes, look for a bright trailed image paralleled by fainter trails on either side.

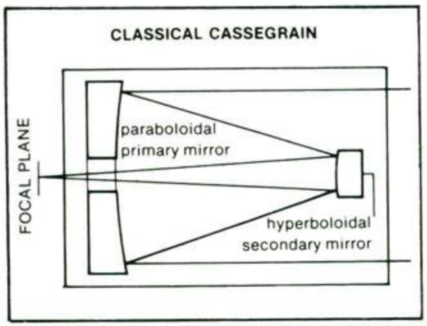
As you watch the space ship traverse the sky, you sometimes can pick out some interesting characteristics: specular reflections from protruding parts or a favorable orientation of a solar panel might cause a sudden surge of brightness. (On several occasions I've seen Skylab rival the planet Venus.)

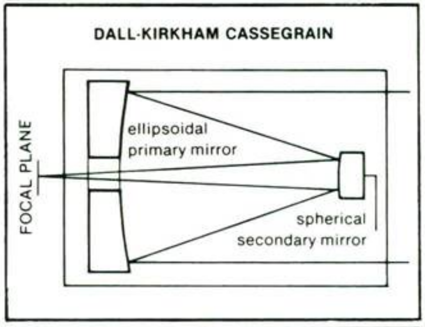
Perhaps the most intriguing view to get is watching a satellite disappear. You'll see it moving along, more or less even in brightness, when for no obvious reason it'll vanish from sight. What's happening is that as the satellite orbits high above us, at some point it passes into the Earth's shadow, thus cutting off its source of illumination. If you watch carefully, you may notice a color change at the same time: the light becomes redder, which is what you'd expect as the Sun "sets" for the satellite.

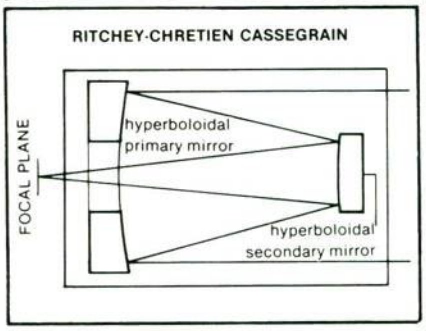
Pulling off a good satellite photo is a bit like catching the passage of a fireball meteor, though with predictions you can do a lot to help your chances of being in the right place and looking in the right direction. And when you've done it, your photo locks forever an image that will never be precisely repeated again.

Like shooting a street scene at night, it's an innovative departure from ordinary still photography, and responding to the challenge can easily be a memorable adventure. Grab your camera, watch the sky, and go try some picture-taking off the beaten path.

WHICH CASSEGRAIN IS BEST???


CLASSICAL CASSEGRAIN
FOCAL PLANE
paraboloidal primary mirror
hyperboloidal secondary mirror

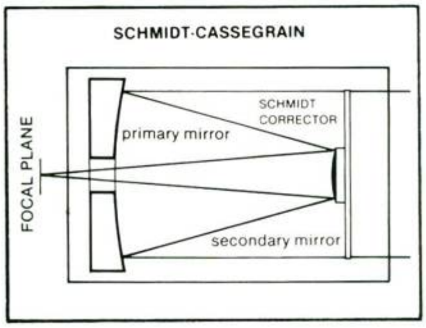

DALL-KIRKHAM CASSEGRAIN
FOCAL PLANE
ellipsoidal primary mirror
spherical secondary mirror

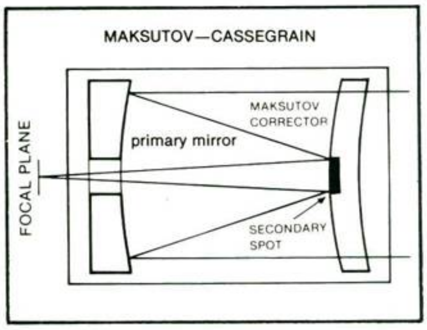

RITCHEY-CHRETIEN CASSEGRAIN
FOCAL PLANE
hyperboloidal primary mirror
hyperboloidal secondary mirror

The Cassegrain telescope is a reflecting type employing two curved mirrors to gain a long focal length. Light is beamed from the main mirror back up the tube to a second mirror, which beams it right back down again and through a hole in the center of the main mirror to the eyepiece. The combination gives the same performance as the long tube Newtonian but in a more compact size requiring a far less massive mount for the same degree of stability. It also places the eyepiece at a more convenient position. The disadvantages of the Cassegrain reflector are the difficulty in parabolizing the short focal length primary mirror to the required degree of accuracy and the open tube construction which also exposes the mirrors to contamination. It also suffers coma. Other than the true Cassegrain system there are two other recognized systems made, which are the Dall-Kirkham and the Ritchey-Chretien. The more popular Dall-Kirkham is cheaper to make than a true Cassegrain but it has extensive coma, making its usable field of view smaller than a true Cassegrain's. The R-C reduces coma to almost zero but suffers from astigmatism and severe curvature of field. None of the above systems is manufactured in large quantities, and when available they can be very expensive compared to alternative catadioptric systems.

THE CATADIOPTRIC

A dramatic improvement over the above is the catadioptric system. It is a combination mirror-and-lens system, offering long focal length in a compact, closed tube. The lens is used ahead of the mirror to correct known faults in the mirror. It combines the best of both mirror- and lens-only telescopes. There are two basic types of catadioptric systems, the Maksutov-Cassegrain and the Schmidt-Cassegrain. The Maksutov uses a thick meniscus correcting lens and the Schmidt uses a thinner aspheric correcting lens. The Schmidt is more difficult to produce than a Maksutov.


SCHMIDT-CASSEGRAIN
FOCAL PLANE
primary mirror
SCHMIDT CORRECTOR
secondary mirror

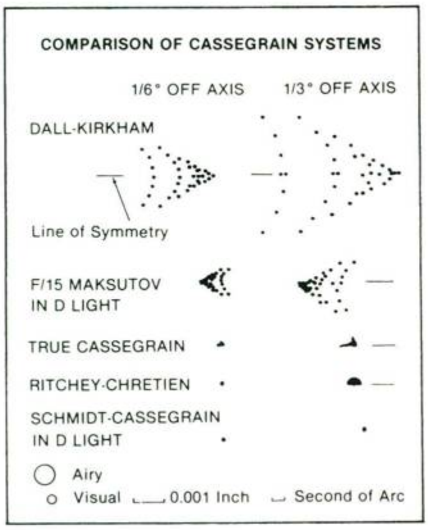

MAKSUTOV—CASSEGRAIN
FOCAL PLANE
primary mirror
MAKSUTOV CORRECTOR
SECONDARY SPOT

Let's look at some of the factors of the catadioptric systems.

OPTICAL ALIGNMENT—Contrary to what many manufacturers say, the Celestron Schmidt-Cassegrain telescopes are relatively easy to collimate when it is needed. Let us state that the Schmidt rarely needs aligning even after transhipment across the world while sustaining rough handling. If the Schmidt needs aligning (only one element is adjustable) it will only take a couple of minutes following easy step-by-step instructions given in the operating manual.

Maksutov instruments are permanently aligned. However, rough handling can cause them to come out of collimation and this renders the system in permanent **decollimation.** This usually requires a return trip to the factory.

OPTICAL CHARACTERISTICS - Chromatic aberration and coma are virtually nonexistent with the Schmidt but are noticeable to a small degree with all Maksutov designs. Off-axis performance of the Schmidt is by far the best compared to other systems.



The on-axis performance of all of the folded systems mentioned is the same. If any one of them is pointed at a point source at infinity, all of the light entering the system will pass through a point at the focal plane of the lens. It is in off-axis performance that these telescopes markedly differ.

The modern computer, in ray-trace techniques, provides an excellent method for evaluating the off-axis performance of an optical system. The illustration is from an article by Ronald Willey, Sky and Telescope, April, 1962. It gives the results of a computer ray trace of the several folded optical systems at 1/6° and 1/3° off axis. Each dot in the pattern is the point at the focal plane through which a given ray through the system will pass. The spread of these dots indicates the amount of distortion. For convenience in evaluating the distortion, the small circle in the lower left of the illustration is the size of the Airy disc for the systems checked. It is evident from these ray tracings that the Celestron Schmidt Cassegrain produces the sharpest images across the entire focal plane.

CENTRAL OBSTRUCTION - Effect on Image Contrast.

A great deal has been said in amateur oriented literature, and by some of the manufacturers whose instruments may be lacking a central obstruction or perhaps boast a slightly smaller central obstruction, about the effects of central obstruction on image contrast. It is desired that maximum image contrast be achieved for viewing certain low-contrast narrow-field objects such as Jupiter and Saturn. The seeing condition (or air turbulence) is the single factor that most adversely affects image contrast when seeking planetary detail through a telescope. Instrument problems that can also adversely affect contrast are: optical figure, collimation, optical smoothness, baffling, and a small increase in central obstruction. Note that the increase in central obstruction is rated as the smallest contributor to adversely affecting contrast.

In a telescope that has no central obstruction and is otherwise perfect, 84% of the light energy from a point source is imaged in the primary maximum or Airy disc. Half of the remainder (7.2%) is in the first diffraction ring. However, since the area of this first ring at the image plane is approximately six times greater than that of the Airy disc, the actual apparent intensity of this first ring will be 1.8% of the intensity of the primary maximum. Now, if the energy in the primary maximum is reduced by 10% by the introduction of a central obstruction, the energy in the first ring would increase from 7.2% to 16%. This would have the effect of increasing the visual intensity of the first ring relative to the primary maximum from 1.8% to 6%, a change that would hardly be detectable. The relative intensity of the second diffraction ring as well as all of the rest would be so low as not to even warrant consideration.

If you wish to play games with advocates of smaller central obstructions, select a night of good seeing, use the Cassini division of Saturn's rings as a test subject and vary the size of the central obstruction by using a set of cardboard circular masks of various diameters. See if they can tell the difference in contrast with the various masks. You will find that a very gross change in central obstruction would be required before any noticeable difference in contrast could be detected.

THERMAL EQUILIBRIUM - All Celestron telescopes are manufactured with aluminum tubes which allow the optics to stabilize and reach thermal equilibrium in the minimum time.

FOCAL LENGTH - Most of the Maksutov telescopes offered are of long focal ratios (f/15 or f/16), whereas Celestron Maksutovs and Schmidts are much faster (f/10 or f/11). For terrestrial photography this means the Celestron is about a full f/stop faster than the other popular units. This in turn means a brighter focusing image and sharper photos since one can shoot at twice the shutter speed required at f/15. Also other popular units vignette seriously on terrestrial subjects. The longer focal ratios do have a slight advantage on lunar, planetary, and some double star subjects but are at a serious disadvantage on deep-sky subjects. The Celestron f/10 and f/11 systems are excellent for all purposes, especially deep-sky. Celestron recently introduced a new accessory R.F.A. (rich field adaptor), for visual use that reduces the focal ratio to f/5 or f/5.5 (a photographic device—the Tele-Compressor— does the same thing photographically).

QUALITY CONTROL - Since inception, Celestron's philosophy has been continuing product improvement. Each year brings new advances in the manufacturing processes of mechanics and optics. Recently we have purchased the most sophisticated and most accurate machines available in the world for our machine shop. We have the most sophisticated optical testing equipment and each instrument is exhaustively tested.

Since we manufacture our own optics as well as mechanics, and also do our own optical coating, we have complete control, with quality control stations set up throughout the manufacturing process.

WARRANTY - Celestron offers a *full* one year warranty. This means 100% of the instrument and accessories plus freight *both* ways so that the customer does not pay a penny if anything is wrong. Normally if something goes wrong with an instrument it will happen in the first few months of usage. However, if some obvious defect due to manufacturing appears several years after purchase we routinely repair the instrument at no charge. This warranty is better than a five or ten year limited warranty offered by others, especially when the clock drive is not covered (the part most apt to need repair), and also when the customer must pay the freight charges at least one way and in some cases both ways. Also some manufacturers offer long warranties that will be useless if within a couple of years they are no longer in business (80% of all new businesses fail within 5 years). In essence, the Celestron warranty is as good, or better, than any other.

ACCESSORIES - Whatever your interests are in a telescope, whether terrestrial or astronomical, Celestron has the most extensive line of accessories for visual or photographic purposes and we are always looking at and developing new products. In addition, we offer the most extensive aperture range . . . 3½ to 14 inches to suit your needs.

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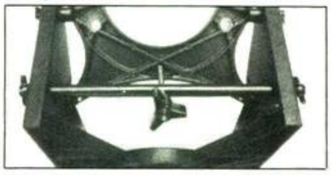

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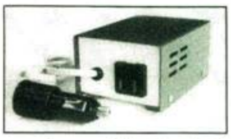

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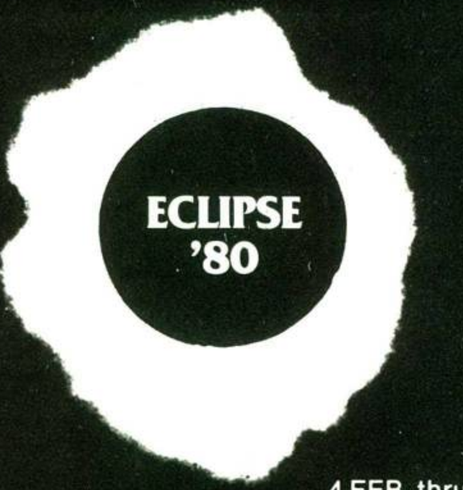

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AstroNews

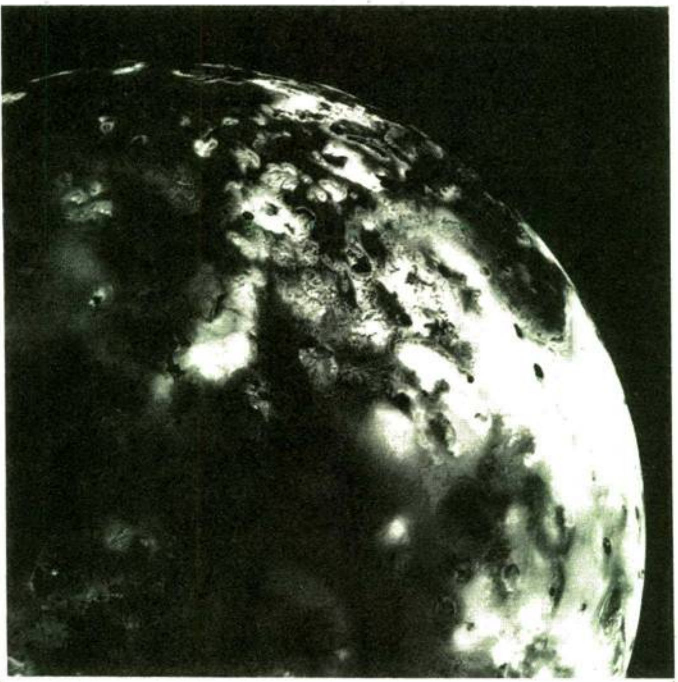
Scientists Study Data From Voyager 1

Voyager 1 has completed its observations of Jupiter and the jovian system, but back on Earth scientists are poring over the data recorded during the encounter. The images returned during the flyby of Jupiter and its diverse family of satellites are being analyzed and studied more closely. Data from the other instruments aboard Voyager 1 are also being processed for a greater understanding of the solar system's largest sub-unit.

Already a number of new things have been learned. Initial analysis of some of Voyager's photos indicated that frequent, large electrical discharges — huge lightning bolts — were a common feature of Jupiter's atmosphere. This has now been confirmed by detection of radio "whistlers" characteristic of lightning, which were recorded by the spacecraft's plasma wave experiment. Since some of these low-frequency emissions were detected when Voyager was closest to Io, there is a possibility that Io, already known to be the most volcanically active body in the solar system, may also have lightning itself.

The widespread presence of lightning in Jupiter's atmosphere again raises the possibility of life evolving there. All the necessary elements and chemicals for life are present in the jovian atmosphere, and it is believed that the frequent, massive electrical discharges could provide the energy for the synthesis of more complex organic molecules. Whether such molecules could survive long enough in the violent jovian atmosphere to become organized into self-reproducing, living organisms is quite another question. But some scientists believe that the presence of such complex molecules could explain the colors of Jupiter's clouds. All the gaseous elements and simple molecules known to be present on Jupiter are colorless in themselves.

Jupiter's famous ring, discovered by Voyager 1, has now been detected by Earth-based observation. E.E. Becklin, C.G. Wynn-Williams, C.B. Pilcher, and J.S. Morgan of the University of Hawaii observed the ring on both sides of Jupiter with the 88-inch Mauna Kea telescope. The observations were made in the infrared, at a wavelength of 22,000 Angstroms (2.2 μm). The ring was estimated to be some 11 magnitudes fainter than Saturn's rings as observed with the same instrumentation.



Scientists now believe the darkest areas on Io may be flows of molten lava spewed from its many active volcanos. This photo of Io's strange surface was taken by Voyager 1 on the morning of March 5, 1979. NASA/JPL photograph P-21227.

Jupiter's violently active satellite Io has been receiving a great deal of attention. Already known for having the strangest and most active surface in the solar system, Io continues to amaze the scientists. The Io pictures imply that its volcanic activity, far more violent and explosive than any seen on Earth, is practically continuous. At least five active regions were easily identified, and a number of others are suspected. The sodium cloud surrounding Io is believed to be a product of the volcanic eruptions, and scientists estimate that the glowing light from the sodium vapor would disappear if the eruptions ceased for more than 20 hours. The cloud, which has been observed from Earth for several years, has never been seen to vanish.

The eruptions could also account for the various other peculiar veils which surround Io, such as the sulfur-filled torus. And another of Voyager's instruments found that three regions on the surface of Io have a temperature between 100° and 200° Fahrenheit, suggesting that they are in reality lakes of molten material, probably sulfur. One of these "lava lakes" is estimated to be as large as the state of Hawaii.

In any case, the apparent youth of Io's surface, immediately noted by scientists when the first close-up pictures came back, has been explained. It only remains to calculate the rate at which Io makes itself over. Preliminary calculations on the basis of known production rates of craters in the inner solar system suggest that craters as small as a half-mile in diameter would be erased on Io in only a few million years. The erosive processes taking place on Io may be capable of even faster action than that.

In one way, the activity of Io should not have come as a surprise to scientists. In an article published just before Voyager's close encounter (in the March 2, 1979 issue of **Science**), J. Peale of the University of California and P. Cassen and R.T. Reynolds of the Ames Research Center proposed that tidal stresses on Io as a result of its proximity to Jupiter together with the gravitational force exerted by the other large jovian "planets" would lead to massive internal melting. The result of such heating would be a world with a large molten core and perhaps only a thin solid outer crust. The authors prophetically suggested that Io could be

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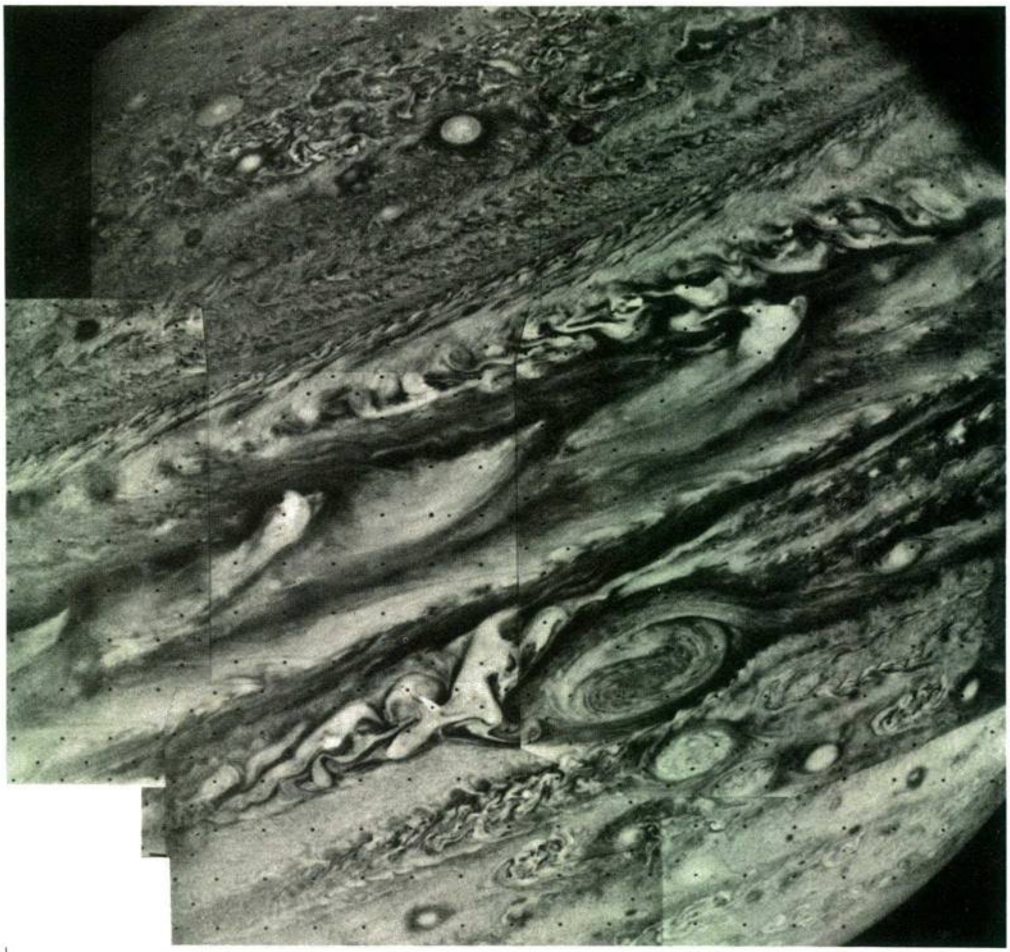


The complex turbulence of Jupiter's atmosphere is clearly seen in this mosaic of nine individual photos taken by Voyager 1 on February 26, 1979. The spacecraft was 4.7 million miles from Jupiter. NASA/JPL photograph P21146.

"the most intensely heated" Earthlike body in the solar system, and went on to speculate that "widespread and recurrent volcanism" could be expected.

Whatever the source of the internal heating — and scientists are not yet convinced that Peale and his colleagues have found the right model — Voyager 1 has laid to rest a mystery about Io which only arose a few months earlier. Writing also in **Science** (February 16, 1979), F.C. Witteborn, J.D. Bregman, and J.B. Pollack of the Ames Research Center reported that spectrophotometric observations of Io revealed an intense transient brightening in the infrared. They concluded that such a burst of brilliance could only be the result of some kind of emission mechanism, but were unable to identify the exact cause on the basis of their evidence.

Three possible explanations were considered. The first, that the brightening was due to an especially bright surface feature rotating into view, was rejected on grounds that such a phenomenon couldn't account for the magnitude of the brightening. The second, which it turns out was the correct explanation, was that the brightening was due to a thermal emission from a hot portion of Io's surface. However, the authors doubted that such an emission could arise from volcanic activity, because, they noted, no spot large and hot enough to account for the observation has ever been observed anywhere else in the solar system!

Although they pointed out that this did not definitely rule out the possibility of such massive volcanic activity, the authors prudently concluded that the most likely explanation for the infrared burst was the third possibility: an emission mechanism arising from a bombardment of Io's surface by electrons due to Jupiter's intense magnetosphere.

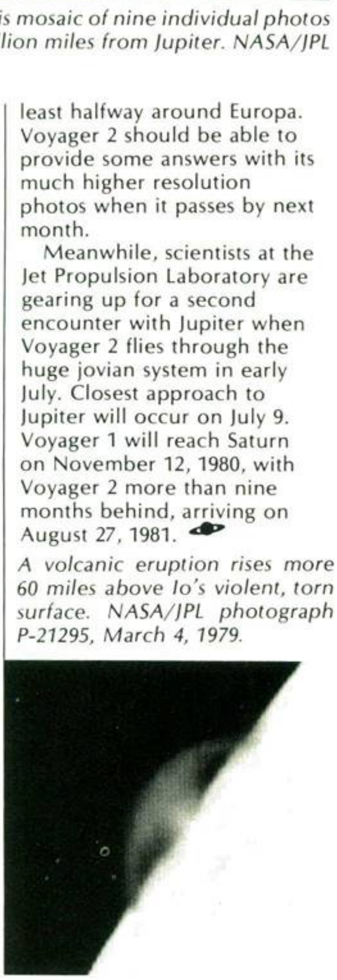
Farther out in the jovian system, the other large "planetary" satellites continue to attract their own attention from the scientists. Callisto, already famed for having the largest impact feature yet seen, turns out to have another such feature as well. This is also a large basin ringed by ridges, but was not immediately identified as such because of the high angle of illumination. These features are believed to be due to the impacts of large meteors on Callisto's surface, probably long ago. Callisto, a low-density world likely composed of a mixture of rock and ice, would have such a low tensile strength that a massive impact would produce "ripples" far across its surface, like a stone dropped in a pond. The cold temperatures would soon freeze the ripples, producing the ringed ridge system seen today.

Io seemingly floats above the stormy clouds of Jupiter's vast atmosphere in this March 2 photograph by Voyager 1. NASA/JPL photograph P-21185.

Voyager 1 did not make a very close approach to Europa (that flyby is one of the assignments of Voyager 2), but the low-resolution images which were obtained showed it to be crisscrossed with lines, looking suggestively like cracks in a planet-wide ice sheet. Although the true nature of the lines is still uncertain, closer study has shown that some are extremely long, stretching at least halfway around Europa. Voyager 2 should be able to provide some answers with its much higher resolution photos when it passes by next month.

Meanwhile, scientists at the Jet Propulsion Laboratory are gearing up for a second encounter with Jupiter when Voyager 2 flies through the huge jovian system in early July. Closest approach to Jupiter will occur on July 9. Voyager 1 will reach Saturn on November 12, 1980, with Voyager 2 more than nine months behind, arriving on August 27, 1981.

A volcanic eruption rises more 60 miles above Io's violent, torn surface. NASA/JPL photograph P-21295, March 4, 1979.



AstroNews

Gravity and PSR 1913+16

6,000 light-years distant, tucked away between the constellations Cygnus and Aquila in the small northern constellation of Sagitta (the arrow), lies the most important discovery for the new science of gravitational astronomy. Over 4 years ago, the unique radio pulsar PSR 1913+16 was detected there, and this strange pulsar has now led astronomers to the first quantitative confirmation of the existence of gravitational radiation.

PSR 1913+16 (the numbers indicate approximate celestial coordinates) was discovered in 1974 by two radio astronomers from the University of Massachusetts, Joseph Taylor and Russell Hulse. They were doing a general survey of the sky, searching for new pulsars with the largest radio telescope in the world, the 1000 foot Arecibo receiver in Puerto Rico.

When the pulsar was discovered to be orbiting a massive but unseen companion, Dr. Taylor, Peter McCulloch from the University of Tasmania, and graduate student Lee Fowler, from the University of Massachusetts, immediately became excited. This type of binary system, the first of its kind to be discovered, had been suggested by Einstein as a source of intense gravitational radiation. According to the theory of general relativity, if two massive objects are orbiting each other at close range, the orbits of the objects will spiral inwards. This is due to energy loss in the system caused by radiation of gravity waves that should exist according to theory.

To explain more clearly this unique and important binary system, Dr. Taylor was recently interviewed in his office in Amherst, Massachusetts. Asked about the relationship of the two stars' mass and distance, he replied: "If the distance between the two stars of PSR 1913+16 were twice what it actually is (435,000 miles), the effect of the gravitational radiation would be too small for us to measure."

How was this unique binary created? "At first we thought the pulsar was created recently, possibly in recorded history, because the pulse rate was the second fastest of any known pulsar (0.059 sec). The fastest pulsar known is the Crab Nebula pulsar (0.034 sec), now believed to be the result of a supernova explosion in 1054 A.D. After 4 years of observations it became obvious that this pulsar was not slowing nearly as fast as the Crab pulsar. We now feel PSR 1913+16 may be about 100 million years old. This is contrary to the idea of a fast pulse rate corresponding to comparative youth."

According to Taylor, the pulsar probably resulted from the supernova explosion of a star with a mass of about 2.8 suns. When this massive star blew up, it split into two spheres of equal mass. If the pulsar were orbiting another star before going supernova, it probably would have been ejected from the system by the violence of the event.

Questioned about the mysterious unseen companion that has a mass of 1.4 suns, Taylor said, "We are quite sure it is not a white dwarf. With a mass of 1.4 suns it would collapse to the size of a neutron star. It could also be a pulsar, but the radio emission cone is not aimed in our direction. It may even be a black hole, but we can't be sure yet."

And what about the ultimate end of these massive stars? If the orbits of the two objects are shrinking, what will finally happen?

The research team estimates that in 300 million years the two stars will collide and produce a tremendous gravitational pulse. 300 million years is a long time to wait for such a pulse, but pulses like that would be the easiest to detect directly by the gravity wave instruments being planned and built now.

"There no doubt are many more binary pulsars in our galaxy," Taylor pointed out. "Right now, two unknown neutron stars may be destroying each other, producing pulses of gravity waves that may be detectable on Earth."

A hypothetical system composed of two objects, each of one solar mass and orbiting only 6000 miles apart, would have a period of less than a minute. This is much less than the 8 hour period of PSR 1913+16, whose components are much more widely separated. But such a close system would experience a complete loss of mechanical energy in only 10,000 years. Such a rate of energy loss is one million times higher than the Sun's total radiation.

Taylor agreed that such a close binary system may indeed exist, but he pointed out that so far no other pulsar binaries have been detected.

Taylor was then questioned about the observing schedule and the necessity of using the huge Arecibo radio telescope.

"We would visit Arecibo twice a year for two weeks. Each day for two hours the pulsar was tracked until it was out of range of the telescope. After recording 5 million pulses we were within an error range of 10% in determining the orbit period of the binary system."

And why Arecibo? "The pulsar is so distant, one of the most distant of the known pulsars. It takes 8 hours, for example, for the Jodrell Bank radio telescope in England to collect the same amount of data that the Arecibo can collect in two to three minutes."

The binary pulsar's great distance also added to the problem of dispersion of the radio beam due to interstellar gas and dust. Using a special dispersion-removing receiver, custom-built by Taylor's group and attached to Arecibo's receiver, they were able to time the pulses accurately to within 0.00005 second.

In four years of careful observation, the orbital period of the pulsar had decreased by only 0.000414 second (1 second in 10,000 years), but such a decrease is consistent with the general theory of relativity. Even more important, this observed rate provides some strong constraints on any alternative theory of gravitation. Generally these other theories predict a greater loss of energy than Einstein's.

PSR 1913+16 also is providing astronomers with other important information about the late stages of stellar evolution. For example, it is the first time the mass of a radio pulsar has been accurately determined, and the first time the precession of a pulsar's spin axis has been observed. A pulsar spins about an axis, causing the hollow cone of intense emissions to sweep around like a lighthouse beam. In a system like PSR 1913+16, the precession of this axis would allow astronomers to see different sections of the cone. This would result in a change in the width and shape of the radio pulse. Observations revealed that the precession does indeed exist, and at the predicted rate.

Presently the precession is moving the observer's line of sight closer to the center of the radiation cone. The observed precession of the pulsar spin-axis thus provides a unique opportunity to determine the actual shape of the pulsar radiation beam in two dimensions.

What are the Taylor group's future plans? "We expect to continue the observation schedule for at least three more years. This added data should reduce the error of the orbit changes from 10% to about 5% ... We also want to study the polarization effect of the gravity waves."

Gravitational polarization is similar to, yet in one important way different from, electromagnetic polarization. Gravity waves passing through a cloud of stationary heavy particles best illustrates the effect. If one particle is chosen as a standard of reference, particles on the left and right would swing away from each other, while particles above and below would swing toward each other. At the next instant, all these motions are reversed.

On the other hand, suppose a gaseous cloud of electrically charged particles were suspended motionless in space. When an electromagnetic wave passes, all the particles will be driven to and fro in the same direction. This direction, together with the direction of propagation of the wave, defines the plane of polarization. A gravity wave, however, would have two planes of polarization.

In a binary system such as PSR 1913+16 the action of a gravity wave is similar to shear waves that result from sound waves meeting with a solid substance. The gravity waves are emitted in all directions but in the orbital plane of the pulsar, the two planes of polarization will be in the orbital plane and at right angles to the orbital plane. Determining the amount of polarization in this binary system will add further proof to the first indirect observational evidence of gravity waves.

Finally, Taylor was asked what was the most important aspect of their discovery and study of PSR 1913+16. "Our discoveries will encourage other gravity wave researchers to look for similar binary systems and to build better detectors that could directly study these waves."

Strange Spectrum

Analysis of the spectra of astronomical objects is one of modern astronomy's most powerful tools. Not only can elemental and chemical constituents be identified along with their relative abundances and other important data, but shifts in wavelength of known spectral lines can indicate relative velocity or other astrophysical processes. Now, an object having the most peculiar spectral characteristics ever seen has been observed, and it is mystifying astrophysicists.

A group of scientists at the University of California (Los Angeles) headed by Bruce Margon observed the spectrum of SS-433 (from the Stephenson-Sanduleak catalog), an unidentified stellar object. SS-433 has an emission line spectrum, meaning that its spectrum is characterized by bright lines rather than dark absorption lines against a bright continuum background. Several of these emission lines cannot be identified with any known atomic or molecular species, which is what prompted the study.

During this study, to the researchers' surprise, they observed the strange spectral lines shifting in wavelength in a seemingly random way even as they watched. For example, two lines which occur near the well-known hydrogen-alpha line at 6562 Angstroms (A), were seen to move by different amounts in opposite directions away from each other. Over a four day period, one line shifted 150 A toward the red (long) wavelengths, while the other moved 70 A to the blue, increasing their separation from each other by 220 A. Even larger shifts over longer periods were also observed.

Such peculiar behavior of emission lines is unexplainable by any known physical process, so SS-433 has quickly become one of the central puzzles in astrophysics. The unidentified object is an X-ray source known as A 1909404 and also seems to be associated with the supernova remnant W-50, which is a variable radio source. Estimates of its distance on the basis of interstellar absorption place it at between 11 and 12 thousand light-years from the Sun.

It may be that SS-433 will turn out to be the first of a new class of cosmic objects as strange in its nature and properties as pulsars and quasars.

A New Cosmic "Yardstick"

Three astronomers observing at Kitt Peak National Observatory have discovered an accurate new "yardstick" for measuring cosmic distances. They are Dr. Marc Aaronson of the Steward Observatory (University of Arizona), Dr. John Huchra of the Harvard-Smithsonian Center for Astrophysics, and Dr. Jeremy Mould of Kitt Peak. Their technique, based on observations at infrared and radio wavelengths, may prove to be the most precise way to obtain distances to the spiral galaxies that populate the universe. And these measurements may well resolve the fundamental questions of just how large and how old the universe is.

One of the most important tasks in astronomy is the accurate determination of cosmic distances. Before this century, only the distances to the nearest stars, found by direct measurement of parallax, were known. Since then, by a series of steps, we learned the limits of our own galaxy and the distances to the nearest galaxies, working on out to the farthest clusters of galaxies and, the most distant of all, quasars.

The basic technique is

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simple. First, you choose a standard candle whose constant luminosity and distance are known. Cepheid variables of identical period, for example, are known to have the same absolute magnitude. Therefore, those which appear brighter to us must be nearer, while the fainter ones are farther away. By application of the inverse square law — a candle twice as far away will be one-fourth as bright — a scale or cosmic ruler can be constructed.

The astronomical distance scale is built up by a chain of assumptions involving overlapping standard candles, using ever brighter standards to span greater and greater distances. Finally, the light of whole galaxies themselves becomes the standard.

It has been half a century since the cosmologist Edwin Hubble first established that the speed at which a galaxy is moving away from us is directly proportional to its distance from us. This proportion between a galaxy's speed and distance is now known as H, the "Hubble constant." And this quantity is of much more than passing historical interest: according to the widely accepted Big Bang theory of the universe, galaxies have been expanding uniformly away from each other since their formation, and the implied age of the universe depends strongly on the value of H.

In the 50 years since Hubble's pioneering work, countless studies have attempted to derive an accurate value for H, with widely varying results. To find its value, we need to know the velocities and distances of a large number of galaxies. A galaxy's velocity is relatively easy to measure from the Doppler displacement of its optical or radio emission lines. The faster the galaxy is moving away from us, the more its spectral lines are shifted to longer wavelengths. Distances, however, have proven to be much more complicated to determine. For distant galaxies whose giant stars are unresolvable, the chain of assumptions is so long that their distances are very uncertain.

A more accurate "cosmic yardstick," then, would be a boon to studies of galaxies and cosmology. Aaronson, Huchra, and Mould found such a yardstick based on a combination of radio and infrared observations. The radio observations, carried out at other observatories, centered on the 21-centimeter emission line from the neutral hydrogen gas that pervades a spiral galaxy. The width of the 21-centimeter line is a measure of the galaxy's rotation speed, which in turn depends on the mass of the galaxy. For spiral galaxies, mass and optical luminosity also go together, since mass and luminosity are both provided largely by stars. The more massive (broad-lined) spiral galaxies contain more stars and are therefore optically brighter than their lightweight counterparts. It stands to reason, then, that the width of the 21-centimeter line should be a measure of a galaxy's intrinsic brightness. And if its intrinsic brightness can be determined from the line width, the observed optical brightness will easily give its distance. Thus a set of simple measurements — the 21-centimeter line widths and the apparent optical brightness — could yield the elusive distances to galaxies.

The first tests of this idea were based on relatively nearby galaxies whose distances have already been estimated by other means. Three years ago the radio astronomers Brent Tully and Richard Fisher did find that the width of the 21-centimeter line correlates with brightness as measured in blue light. But the Tully-Fisher correlation was not perfect and therefore could not be used to derive reliable galaxy brightnesses from the 21-centimeter line widths alone.

Aaronson and his co-workers suspected that this difficulty could be lessened by measuring galaxy brightnesses in the infrared rather than in the blue. Their hunch was right — in the infrared, intrinsic galaxy brightness correlated much better with the 21-centimeter line width. Furthermore, the Aaronson-Huchra-Mould relationship is based on a firm physical footing. In the infrared, you measure the long-lived red stellar population common to all spiral galaxies. The blue-light measurements used by Tully and Fisher are likely to be dominated more by the vagaries of dust absorption and short-lived blue stars, which differ from galaxy to galaxy.

Aaronson, Huchra, and Mould believe that the infrared/21-centimeter method is one of the best ways to determine the Hubble constant. They are scheduled to continue their infrared observations on two of the Kitt Peak telescopes this spring. By combining these observations with 21-centimeter results for the same galaxies, they hope to pinpoint at last the value of the Hubble constant, H.

The Solar Polar Mission

So far the exploration of the solar system, far-reaching as it has been, has actually been confined to a single definable region: the ecliptic. The ecliptic is the plane defined by the orbit of Earth, and the orbits of the other planets (except Pluto and, to a much lesser degree, Mercury) all lie within a few degrees of this plane. The ecliptic is approximately the plane of the Sun's physical and magnetic equators.

Space scientists have long suspected that many of the conditions and phenomena observed from the ecliptic, such as the solar wind and various other electromagnetic interactions, may be quite different in the vast spaces which lie outside the ecliptic. An "out-of-ecliptic" space mission could provide much-needed data on the Sun and its environment by studying the Sun's structure and emission as a function of latitude from the solar equator to the solar poles.

Such a mission has now been planned. NASA and the European Space Agency (ESA) have recently signed an agreement for a joint International Solar Polar Mission (ISPM) to be launched in 1983. ISPM will be a double mission involving two spacecraft, one each being supplied by NASA and 11-member ESA. ESA will also supply the software and personnel to manage and support ESA flight operations and data processing at the U.S. base facility. The Jet Propulsion Laboratory (JPL) in Pasadena, California, has been assigned to manage the NASA effort for NASA's Office of Space Science. JPL will also manage the development of the NASA spacecraft system. The Space Transportation portion of the Solar Polar Mission (employing the Space Shuttle for launch) will be managed by NASA's Johnson Space Center in Houston. The European effort will be run by the European Space Technology Center in Noordwijk, The Netherlands.

It is not as easy as it might seem to place a spacecraft in an out-of-ecliptic solar polar orbit. Interplanetary probes have traditionally been launched on trajectories in the general direction of Earth's motion in its orbit, thereby taking advantage of the Earth's own velocity as a starting "boost," or in the opposite direction if the goal (such as Venus or Mercury) lies closer to the Sun than Earth. All such trajectories therefore lie in or very close to the ecliptic. In order to inject a spacecraft into a solar polar orbit, the velocity of Earth in its orbit must first be overcome, and this is far from being a minor problem.

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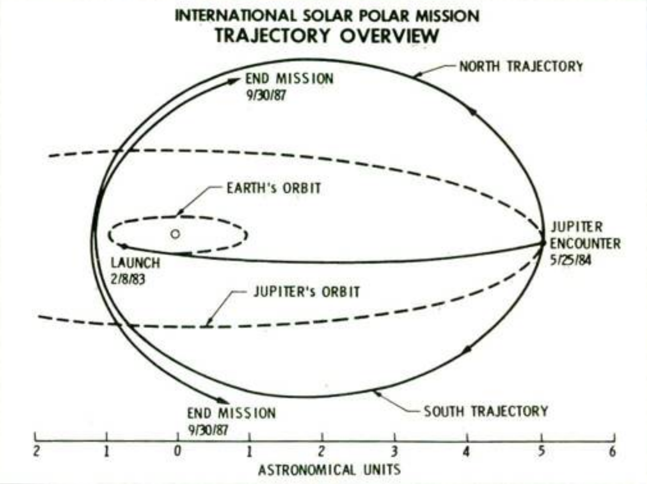

INTERNATIONAL SOLAR POLAR MISSION
TRAJECTORY OVERVIEW

Voyager's New Worlds

This editorial appeared in the April 9, 1979 issue of **Aviation Week and Space Technology** and is reprinted here with their permission.

Voyager's New Worlds

The 422-million mile space journey of Voyager 1 to Jupiter is both a triumph and a tragedy of man's endeavor to explore the universe.

It is a triumph because he was able to send two spacecraft on an 18-month voyage that discovered six basically new worlds hitherto only dimly perceived by human reconnaissance, and this is adding a tremendous store of knowledge to man's perception of his universe.

It is a tragedy because it offers a prime example of how shortsighted budgetary bean counters have passed up a priceless opportunity to reconnoiter all of the outer planets on a Grand Tour. Jupiter, Saturn, Uranus, and Neptune are now in a relatively favorable position to Earth that will not occur again for another 180 years, and the Voyager mission originally was planned to sweep by them all in a truly celestial grand tour. Congress approved the mission in the Fiscal 1972 Budget, but the Office of Management and Budget (OMB), imbued with post-Apollo parsimony, put the squeeze on NASA the following year. Good gray Jim Fletcher, then NASA administrator, made the decision to pare down the Grand Tour to just Jupiter and Saturn and parcel the money among other programs.

The wealth of new knowledge pouring in from Voyager 1 operations near Jupiter again emphasizes the penny-wise pound-foolish vision that OMB budget squeezers have imposed on the vital growth of the U.S. space program.

The Voyager missions are just beginning. Voyager 2 will enter the jovian environment in July and provide new vistas of the fascinating planet, while both Voyagers will scan Saturn in 1980 and 1981.

Voyager has sent to man on Earth the most spectacular pictures of his universe since the shadowy television images of Neil Armstrong and Buzz Aldrin climbing down the ladder of Eagle onto the surface of the Moon. While Armstrong's historic footsteps were carried by television all over the world, the U.S. commercial television networks have once again betrayed the American public by ignoring Voyager, even as they did the dramatic Viking landings on Mars in 1976.

It is a grave tragedy that U.S. television network values are so shallow that they repeatedly ignore the opportunity to perform genuine public service by widespread coverage of the most outstanding events of our century.

Voyager 1 has not had an easy voyage. It has triumphed over many problems during its 18-month transit with a combination of excellent spacecraft design and equipment guided by human ingenuity that can function over the vast distances of outer space. Its first triumph was the exploration of a mini-solar system with a clarity and detail never before possible.

Voyager 1 provided spectacular vistas that can be appreciated by most Earth observers, in addition to a growing treasure of scientific knowledge that will keep analysts busy for years. Among the unforgettable scenes were:

- The great red hurricane swirls of the Great Red Spot.
- The live volcanic activity on Io and the black smudges of fresh cinder cones dotting its surface.
- The hitherto invisible rings around Jupiter and the startling contrasts seen in five of its moons.

The performance of Voyager 1 is a triumph for the Jet Propulsion Laboratory team that designed and built it with the assistance of 36 major subcontractors and research centers. Of particular importance to Voyager's performance was its three-axis stabilization system that enabled its camera platform to swing in all directions. The imaging package included the vidicon cameras made by General Electrodynamics Corp., Dallas, Texas, and the imaging science electronics built by Xerox Corp. Electro-Optical Systems, Pasadena, California. The launch from Cape Canaveral in September 1977, was powered by a Martin Marietta-General Dynamics Titan-3 Centaur rocket. NASA's deep-space tracking network and JPL's processing lab converted Voyager signals into stunning scientific discoveries.

As in all great technical triumphs, there are many people who contributed to the Voyager program from its inception to successful operation. Among those who merit special attention are:

Bob Kraemer, Don Hearth, and Don Rea of NASA for their conception of the grand tour mission and adaptation of it to the Voyager Jupiter/Saturn mission, aided by Dan Herman and Ichtiaque Rasool in later stages; and

Mike McElroy of Harvard and James Van Allen of the University of Iowa for their science presentations that outlined the mission potential, and Mike Mitz for his science payload work.

Key individuals in the JPL spacecraft design team were that old reliable Harris (Bud) Schurmeier, the first project manager, Ron Draper and Bill Shipley of spacecraft design, and Jim Long on multiple planet trajectory planning.

Warren Keller and Art Reetz of NASA headquarters deserve special mention for their insistence on a $15-million hardening program for the Voyagers to enable them to survive the intense jovian radiation for the closer look that revealed the details of volcanic Io.

And so Voyager 1 in its brief but intense flyby past Jupiter added more to man's knowledge of this beautiful and dynamic planet than has been amassed in the hundreds of years of prior stargazing, and is now coasting onward toward Saturn. Meanwhile, Voyager 2, the backup spacecraft, is heading for the jovian environs in July and probably will emphasize once again the priceless treasure of new knowledge that space technology is bringing to man on Earth.

-- Robert Hotz
Editor, **Aviation Week & Space Technology**

A solution, which will be used in ISPM, is to send the spacecraft first to Jupiter, and then make use of that planet's immense gravity to swing the trajectory around and up out of the ecliptic.

Both of the ISPM spacecraft will be launched simultaneously from the Space Shuttle and then directed by a booster rocket on a trajectory in the ecliptic plane to Jupiter. After the Jupiter encounter, the two spacecraft will swing back toward the Sun on paths — one northbound and the other southbound — that are essentially mirror images of each other.

They will pass over the north and south solar poles, swing back through the ecliptic plane, pass respectively over the other solar poles, and then fly back out to the vicinity of Jupiter's orbit. Because of the vast distances involved, the period from launch until shortly after the second pair of solar passages will be approximately five years.

In addition to the primary mission objectives of studying the Sun's structure and emission at high solar latitudes, ISPM will also investigate the interplanetary medium during the initial Earth-to-Jupiter voyage, and also the jovian magnetosphere as the spacecraft fly by Jupiter and are deflected by its gravity to their solar trajectories.

Ion Engines for Space Propulsion

A unique propulsion system that uses the Sun's energy to provide electrical power for ion engines will be developed by NASA's Marshall Space Flight Center in Huntsville, Alabama. The system, known as a Solar Electric Propulsion Stage (SEPS), will first be used on the proposed flyby mission to Halley's Comet. After the flyby of Halley's Comet, the spacecraft will proceed to a rendezvous with the comet Tempel II.

Subsequent missions proposed for SEPS include high-energy planetary and Earth-orbital missions. Start-up of the comet mission is scheduled for inclusion in NASA's 1981 budget proposal to Congress next year.

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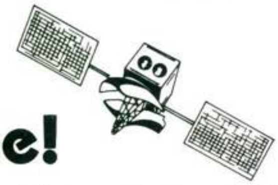

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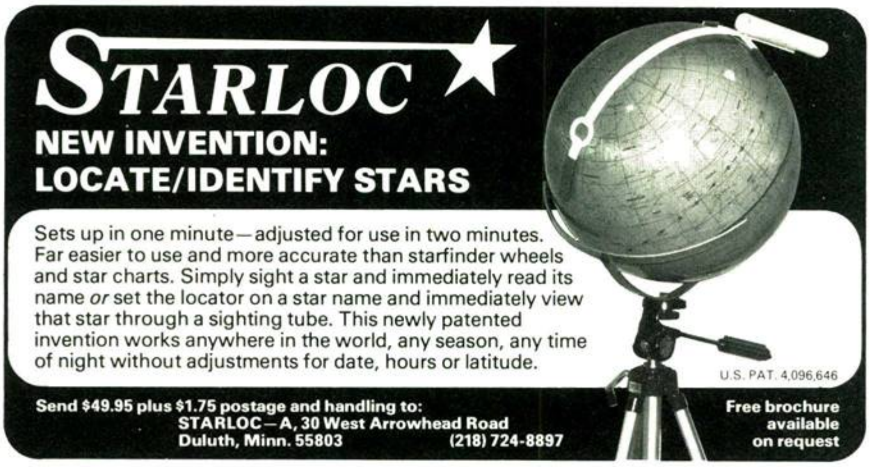

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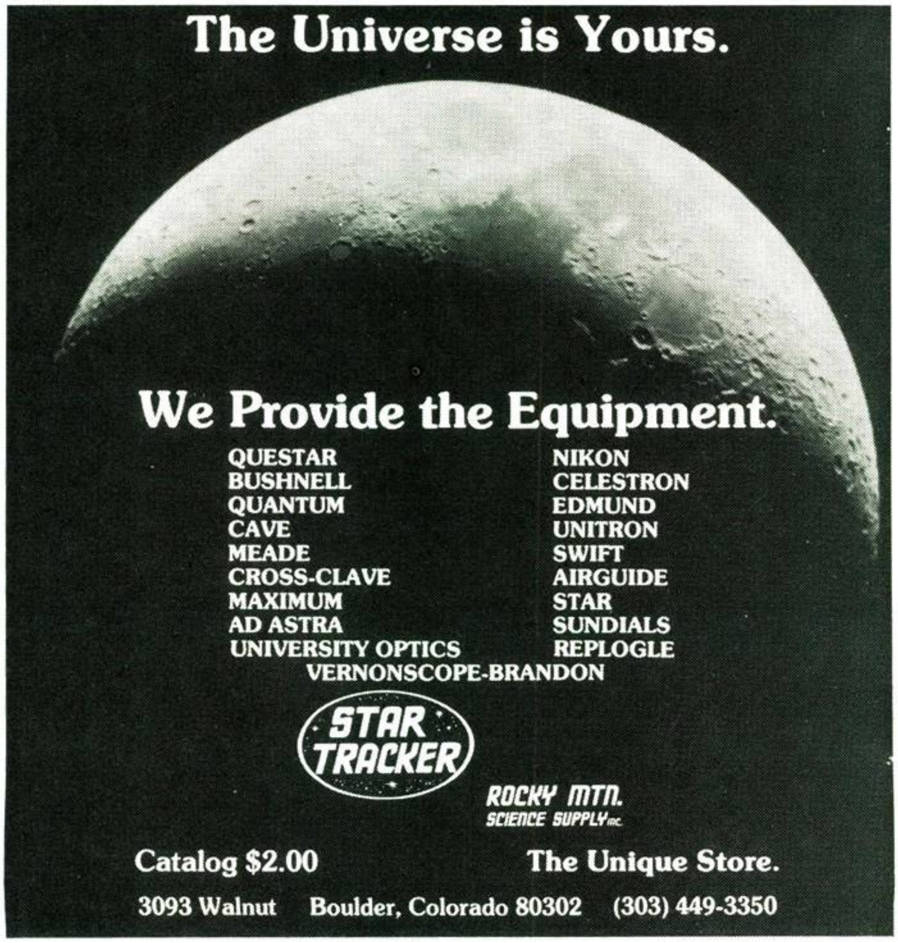

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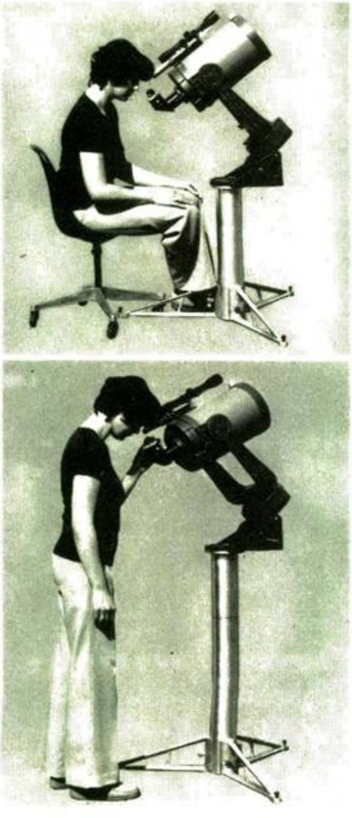

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WANTED — Photos of the February total solar eclipse in all phases. If you have information, please write James N. Graves, 401 S. Park Dr., Austin, TX 78704.

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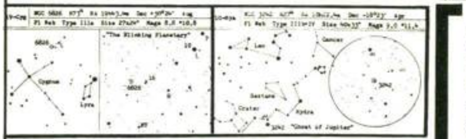

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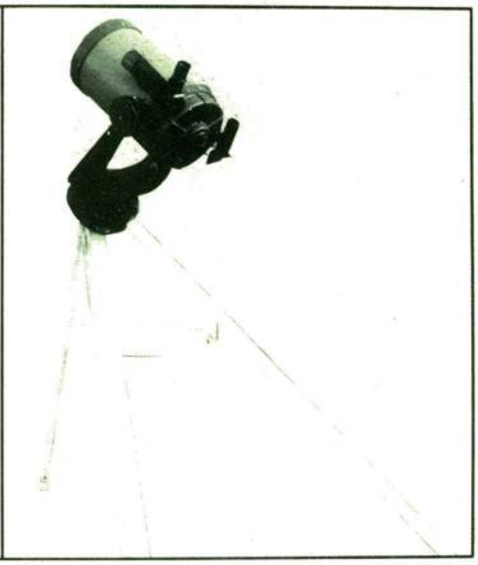

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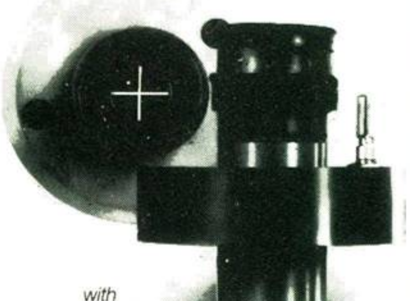

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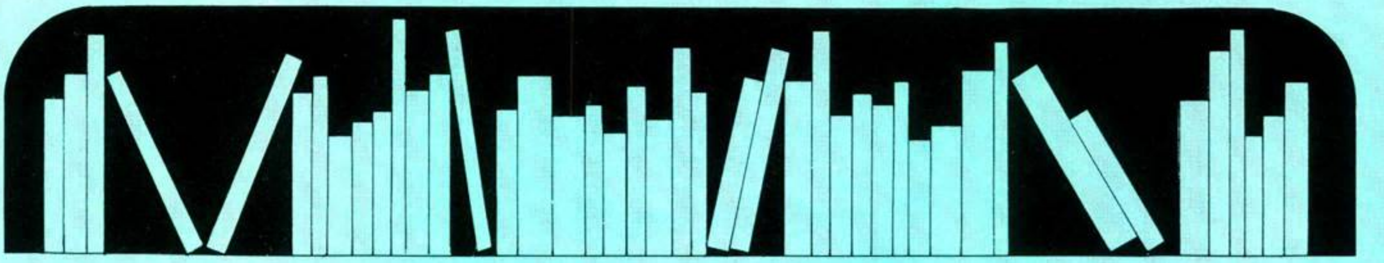


ASTRONOMY REVIEWS

The Planets: A Cosmic Pastoral

by Diane Ackerman

159 pages, hardcover, $6.95*
William Morrow & Co. (1976)

If your fascination with astronomy is closely matched by a love of words, especially puns and other kinds of word-play, exotic names and terminology, and the little-used riches stored up in dictionaries, you may well enjoy this book of poetry about the planets. Diane Ackerman approaches the subject matter of astronomy as a layman — a very well-informed layman attentive to accurate detail. What she brings to it is not professional expertise but fascinated enthusiasm. As she herself says in the dedicatory poem to Carl Sagan, "Knee-deep in the cosmic overwhelm, I'm stricken / by the ricochet wonder of it all." Her book of poetry is essentially a song of praise — praise of the planets as the remarkable worlds they have been revealed to be by recent planetary science and space exploration.

Each planet in order, from Mercury through Pluto, is encountered and explored in its own poem or sequence of poems, and there is a poem on a Viking launch at Cape Canaveral and one on comet Kohoutek. The sections are headed by photographs from NASA or, for the outer planets, from major observatories, and the poems often refer directly to features of the photographic images.

The language of Ackerman's poetry is densely packed with images, so each metaphor or simile seems to be trying to outdo the one before. The overall effect is of a surface encrusted with showy ornament. Breathless, wondering awe is the dominant tone. There is visual as well as verbal play in this poetry — in several cases the appearance of the printed text on the page imitates some feature of the particular planet. "Saturn" is written in stanzas with several shorter lines indented before and after a pair of longer lines in the middle, so if you squint at the page, each stanza looks like Saturn in a small telescope! One of these stanzas will give you a taste of the poetry and of how Ackerman handles her astronomical subject matter (unfortunately, we can't reproduce the visual form here): "In a seaquarium big enough / Saturn would float! lighter / than rock, or water. I marvel / it even holds together: / hydrogen-clotted ice, frozen / methane and ammonia, all lathered to a gaudy slush, / like Jupiter a bit, only colder, which may be why / the weatherworks and the lazy / cloud-roll idle as they do, / and ammonia freezes out / as a yellow blizzard, snowing / deep into the planet-ball."

Ackerman's primary aim is surely to infuse the reader with her own excitement at the phenomena of the planetary system. Her zest doesn't flag as she envisions planet after planet, seeing a future possibility of actual human ventures to these other worlds, all with a vividly sensory imagination. She doesn't ignore Earth either — far from it. The longest section in the book is devoted to Earth — with the all-important difference that she looks at Earth *as a planet*. It's not only new understanding and new images of other worlds that the space missions have brought us, but a new vision of our own. As Ackerman puts it, "Mars and Jupiter stud the sky with light. / I watch them nightly, and try to understand // that I am on a planet, a *planet*, like they are / planets." A sequence of nine poems, including one about Earth's moon, are devoted to this planet. One poem, called "Rapture of the Deep", records the poet's first entry into an alien world on her own planet — the deep sea that is our ancestral home. Another poem in the "Earth" sequence celebrates the world that is the poet's own body and mind, listing, with robust and definitely unsqueamish enthusiasm, everything from intestinal bacteria to DNA.

With the outer planets, where there is neither experience nor a wealth of scientific knowledge to draw on, the poetry is often more fanciful than truly imaginative. Uranus is accorded a play — a sort of cosmic farce, with scatological humor appropriate to its name if not its nature — where Newton, Herschel, and other eminent men from the history of British astronomy, on a spaceship en route to the planet, debate what to expect and carry on in a manner not at all befitting their dignity. With "Pluto", the poet takes the occasion to review her poetic venture into space — "In my 26th year / I left the planet that bore me."

This young woman has not only left the objects and concerns of centuries of poetry and thought — she has ventured boldly into the breach of the "two cultures," flinging a confident challenge to the entrenched notion of an opposition between poetry and science. This, whatever the faults of her first book, is praiseworthy. For art — and poetry, as one of the arts — has, and should be recognized as having, as much a function in a scientific and technological era as in earlier times. For it is to works of art that we must look for an expression of the experience of living in a world that has been changed practically and conceptually by astronomical and other discoveries. Poems and paintings enable us to see the new things and aspects of our world. *Eleanor Berry.*

**Also available in paperback for $3.95.*

◆

Mars, The Red Planet

by Isaac Asimov

222 pages, hardcover, $7.95
Lothrop, Lee and Shepard Co. (1977)

The Viking missions to Mars were second only to the Apollo moon landings in public appeal. Many were fascinated by the lure of mankind's first attempt to examine extraterrestrial life. Anyone caught up in the excitement of the Viking missions, or Mars exploration in general, can do no better than to let Asimov introduce them to Mars.

Beginning with our Sumerian ancestors who saw Mars as a demon and a war god, Asimov marches through time and discovery in a systematic way, bringing us right up-to-date with the Viking results. The book is aimed specifically at the uninitiated. Asimov assumes the reader knows virtually nothing about Mars, so he explains everything in clear, straightforward language. Comparisons and analogies are everywhere. He uses over 60 tables to compare virtually every imaginable aspect of Mars, its atmosphere and satellites, with similar characteristics of Earth and the moon. In many cases, Mercury and Venus are also included in the tabular material making this book, in part, an introduction to the inner solar system.

One possible detraction with Asimov's strictly chronological approach is that he doesn't get around to telling us what Mars is really like until more than halfway into the book. This detective story approach, leaving the interesting stuff till the end, has a certain logic behind it. Knowing what we thought Mars might be like makes knowing what it really is all the more fascinating. Initially, the lure of Mars was more due to false notions about the planet rather than correct ones, but Asimov puts it all into perspective.

This is not a book for anyone who has avidly followed the Viking missions and their results. Asimov's treatment is relatively brief and basic, but it could hardly be otherwise. The objective was to write a reader's first book about Mars, and as such it is excellent. Typically, no major point is overlooked, nor are there any major errors in fact or concept.

Two small blemishes are a reference to the U. S. Naval Observatory's refractor having a 26 inch "mirror" (actually a 26 inch objective; refractors don't use mirrors), and an assertion that Earth appears in Mars' sky as bright as Venus does in Earth's sky. Actually Earth would appear about one magnitude fainter in the Martian sky. However, these two points are extremely minor. *Terence Dickinson.*

NEW BOOKS

The New Solar Physics
edited by John A. Eddy

214 pages, hardcover, $17.50
Westview Press (1978)

In recent years, solar physics has been quietly doing some rather profound reassessing because of four developments: global solar oscillations, a persistent lack of the predicted neutrinos, historical evidence for solar inconstancy, and a new view of the solar wind's role. This book is a record of the papers presented on these four topics at an American Association for the Advancement of Science symposium held in February 1977. Although the papers are technical for the most part, there is much in the historical section which will be of interest to the layman.

The Saturn System
edited by Donald M. Hunten and David Morrison

420 pages, paperback, no price given
NASA (1978) [order as NASA Conference Publication 2068 from NTIS, Springfield VA 22161]

What's the current wisdom about Saturn and its family of rings and moons? NASA assembled experts in February 1978 as part of their planning for the proposed Saturn Orbiter Dual Probe (SOP^2) mission. Also covered were what's expected to be learned from the Voyagers' encounters in 1980 and 1981.

Observatories
by John D. Callendar

64 pages (illus.), paperback, $3.95
Russell-Winthrop Book Co. (1978)

This book is one of a projected guidebook series, and contains a basic description of each of 21 major observatories (mostly in the U.S.).

The Solar System
by John A. Wood

196 pages, hardcover, $10.95*
Prentice-Hall (1979)

The Solar System is a short survey of the known facts about the Sun's 9 planets and the various other minor bodies around it. The author, a scientist at the Harvard-Smithsonian Center for Astrophysics, has done research on meteorites and lunar samples. Accordingly, the book emphasizes the "rocky" aspects of the subject, and presents a view of what might be termed solar system geophysics, but which doesn't ignore the astronomical background, either.

**Also available in paperback for $6.95.*

Effective Astronomy Teaching and Student Reasoning Ability
by Dennis Schatz et al.

about 250 pages, paperback, $6.50
University of California, Berkeley (1978)
[available exclusively from the Astronomical Society of the Pacific, 1290 24th Ave., San Francisco, CA 94122]

This book, the result of a workshop sponsored by the American Astronomical Society's Task Group on Education in Astronomy, compiles a great amount of materials for any teacher who's putting together a course on astronomy. The majority of the book has evaluations of readings, lab exercises, and films, and there are 5 appendices to help set the teacher straight on what's available, and where to look for it. A person studying on their own would also find much in it of use, if only as a "guide to the literature."

Proceedings of the Ninth Lunar and Planetary Science Conference

3973 pages, 3 vols., hardcover, no price given
Pergamon Press (1978)

The Ninth Lunar and Planetary Science Conference was held in Houston, Texas in March 1978, and in these 3 massive volumes, the reports and papers of the participants are presented. The bulk of the papers are technical, but a few have material and photographs of interest to the informed layman.

Mare Crisium: The View from Luna 24
compiled by the Lunar and Planetary Institute

709 pages, hardcover, $40.00
Pergamon Press (1978)

In August 1976, The Soviet Union's unmanned spacecraft Luna 24 landed in the southeastern part of Mare Crisium, and returned a 1.6 meter core sample to Earth. This book is the proceedings of a conference on that sample held at Houston in December 1977. The papers are aimed at the professional scientist and the book is a companion to the 3 volumes of the **Proceedings of the Ninth Lunar and Planetary Science Conference.**

Applications of Early Astronomical Records
by F. Richard Stephenson and David H. Clark

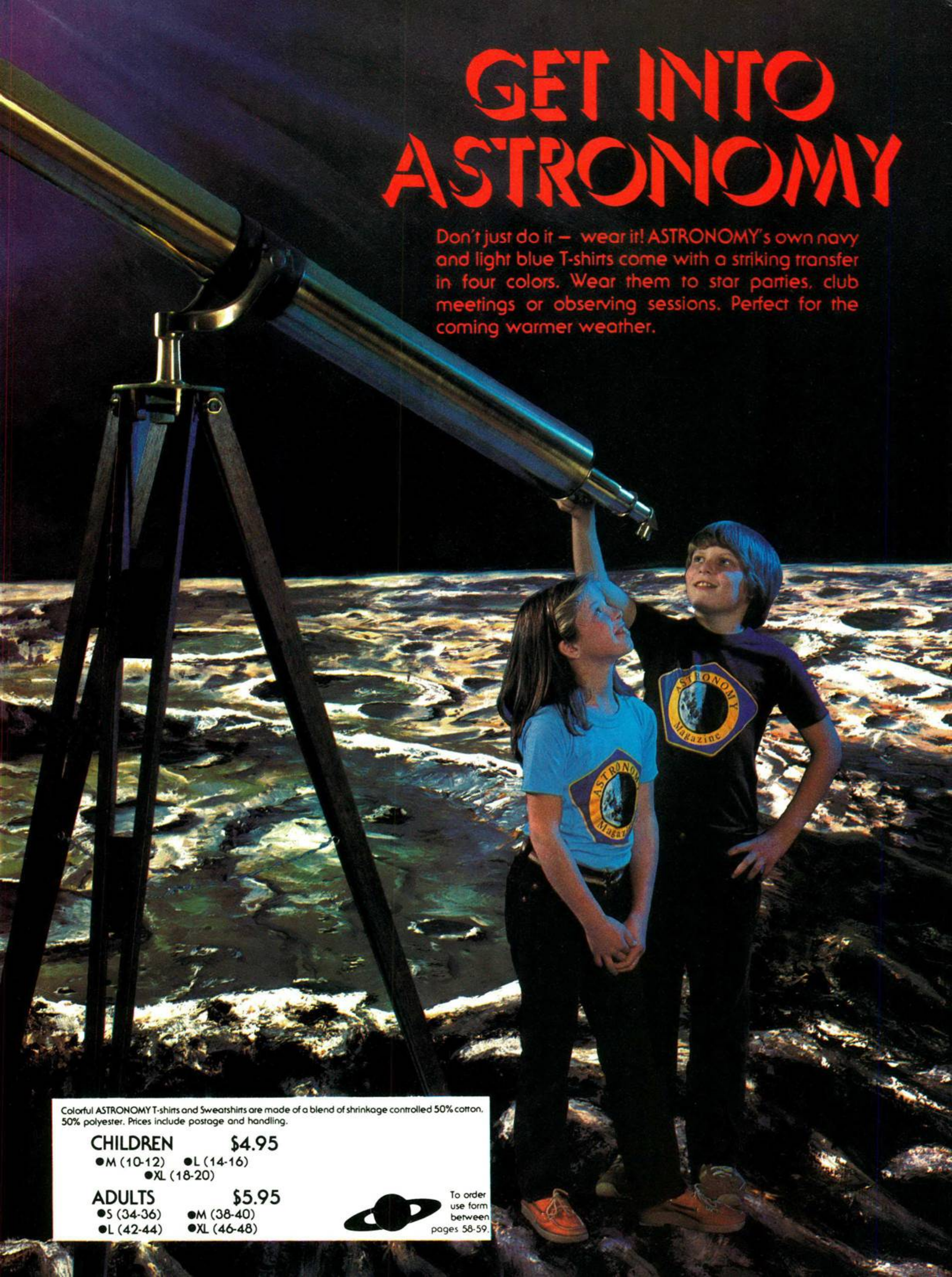
114 pages, hardcover, $12.00
Oxford University Press (1979)

Astronomical observations recorded in antiquity provide a valuable record which astronomers have only recently begun to exploit fully. The Chinese records of sunspots have become very important for certain theories of solar variation, to name just one example. The authors cover the sources of records and then deal in detail with pre-telescopic observations of solar eclipses, novae and supernovae, and sunspots and aurorae. The exposition is on a level that the interested layman can follow and appreciate.

Cosmology and Geophysics
by Paul S. Wesson

240 pages, hardcover, $24.95
Oxford University Press (1979)

Several theories of gravitation currently exist, and physicists have expended much ingenuity in working out their implications. This book provides an overview of these cosmologies, and their possible (and observable) effects on the Earth. The reader is assumed to be comfortable with physical and mathematical arguments.



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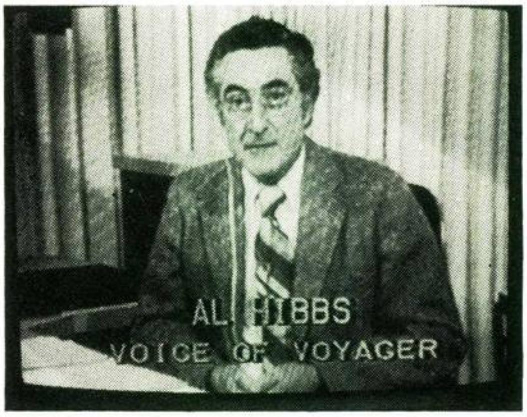

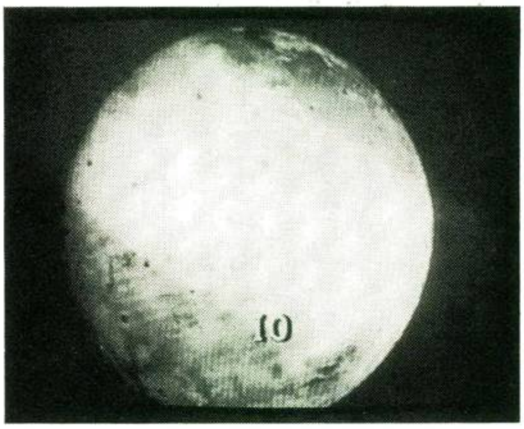

During the Voyager I flyby mission, thousands of black and white and color (imaging) high resolution photos were transmitted back to earth and the JPL in Pasadena. At JPL, for 12 hours (March 4,5 and 6), project scientists produced a "television event" wherein they shared these Voyager I transmissions, their analysis of the received data, and their interpretations of the importance of the data with a small, select group of scientists and observers worldwide interconnected via geo-stationary communication satellites. **The public was also invited** to witness this coverage through cable television facilities throughout the United States. This unedited, as-it-happened event is available on ½ inch (¾ inch on special order) BETA and VHS format videotape. You witness not only the event, but the reactions of top project scientists as the data was received!

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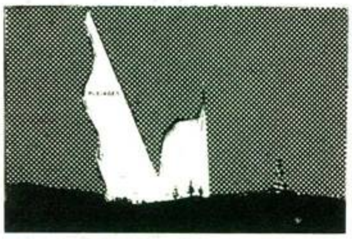

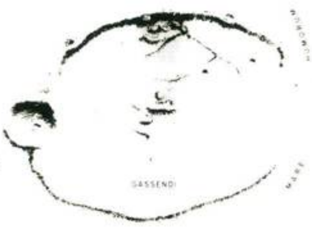

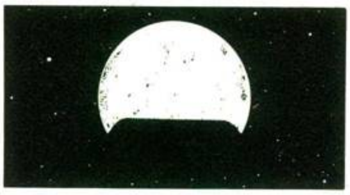

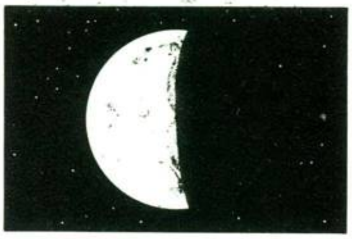

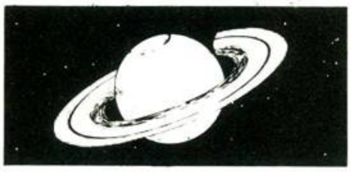

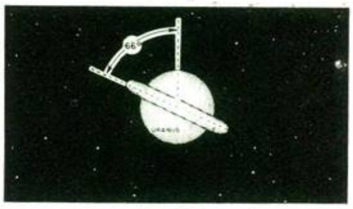

IDENTIFICATIONS

1. Zodiacal light with spurious lobe. 2. Color phenomena (shaded areas) in lunar crater. 3. Distorted shadow during lunar eclipse. 4. Radial spokes on Venus. 5. Planet shadow with "wrong" curvature on Saturn's rings. 6. Sketch of ring of Uranus seen in 1847.

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STAR DOME

JUNE

by
Dewey Schwartzenburg
and
James Mullaney

If, as John Donne said, the winter solstice is "the yeares midnight," then June brings us the noon of the year: the day of the summer solstice, the longest day of the year. This year the solstice falls on June 21 (to be precise, at 23:56 UT, nearly midnight in England but early in the evening in North America). Because of the way our calendar now works, the solstice can vary from June 20 to June 22, so this is an "average" year.

The summer solstice is also known, somewhat incorrectly, as Midsummer's Day. This day was once celebrated with great festivity, but modern society, with its general indifference to those details of astronomical phenomena which so fascinated our ancestors, no longer takes notice of Midsummer's Day. In the Middle Ages, the Christian Church, possibly to suppress the old pagan observances of the solstice, assigned the observance of the Nativity of St. John the Baptist to Midsummer's Day — which at that time fell on June 24. Much more important in the Middle Ages than it has been ever since, St. John's Day was part of a calendrical cycle — the birth of Jesus was celebrated on the winter solstice, and so that of his "forerunner," John the Baptist, was observed on the summer solstice six months earlier. A remnant of the old pagan observances was probably preserved in the tradition of lighting great bonfires on St. John's Eve (June 23), a tradition observed until recent times throughout Europe.

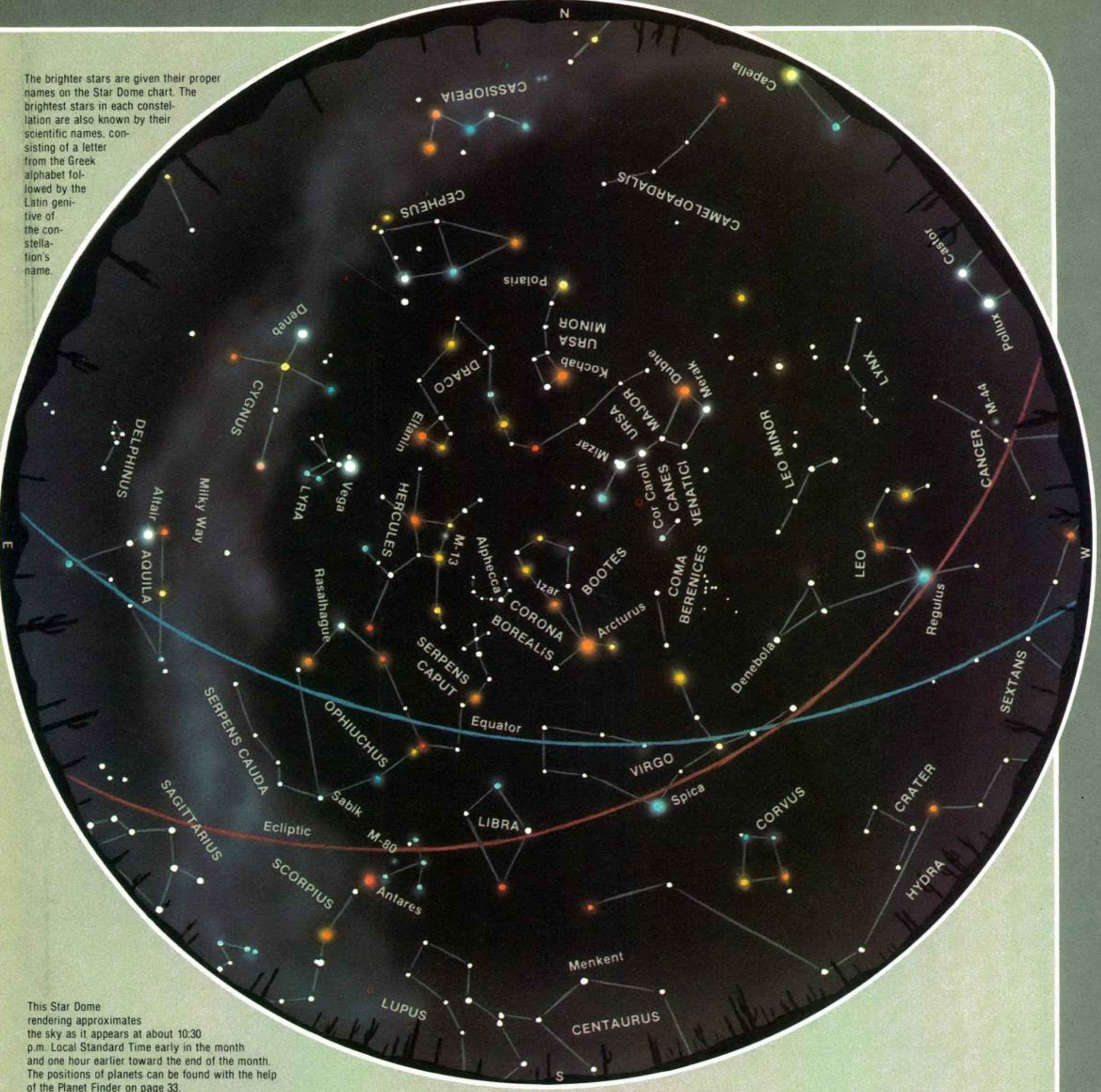
St. John's Eve was also regarded as a sort of "Halloween," a night when witches and warlocks, wraiths and demons gathered together for a satanic festival. This tradition likely reflects the actual survival into the early Middle Ages of full-fledged pagan religious observances of the summer solstice, carried on secretly in remote places. The reputation of St. John's Eve as a night of satanic celebration would have come about because of the Church's condemnation of pagan festivals as demonic rituals of witchcraft and devil worship.

St. John's Eve is the "night" of the Russian composer Modeste Moussorgsky's unfinished work, "A Night on Bald Mountain," a musical picture of that night's frantic, evil celebration. (A version of Moussorgsky's work arranged by Leopold Stokowski was made famous by its inclusion in Walt Disney's animated movie **Fantasia**, as well as by its use in the movie **The Wizard of Oz.**)

The belief in St. John's Eve as a night of mystery and strangeness, when occult powers and hidden forces become manifest, is also reflected in Shakespeare's comic play **A Midsummer Night's Dream.** Two pairs of lovers become entangled in the machinations of the fairies of the forest, while the sprite Puck causes all sorts of trouble for everyone, including a group of country bumpkins attempting to rehearse a ridiculous romantic play. With the coming of dawn, though, all the problems and confused relationships get straightened out and everyone lives happily ever after — or at least until the next Midsummer's Night.

Perhaps the most famous historic observance of Midsummer's Day is the one we actually know least about, namely, that which took place at Stonehenge in England long ago. As is well known, the Sun on the day of the summer solstice is seen to rise directly over the Heel Stone at Stonehenge when observed from the central circle.

The brighter stars are given their proper names on the Star Dome chart. The brightest stars in each constellation are also known by their scientific names, consisting of a letter from the Greek alphabet followed by the Latin genitive of the constellation's name.


N
Capella
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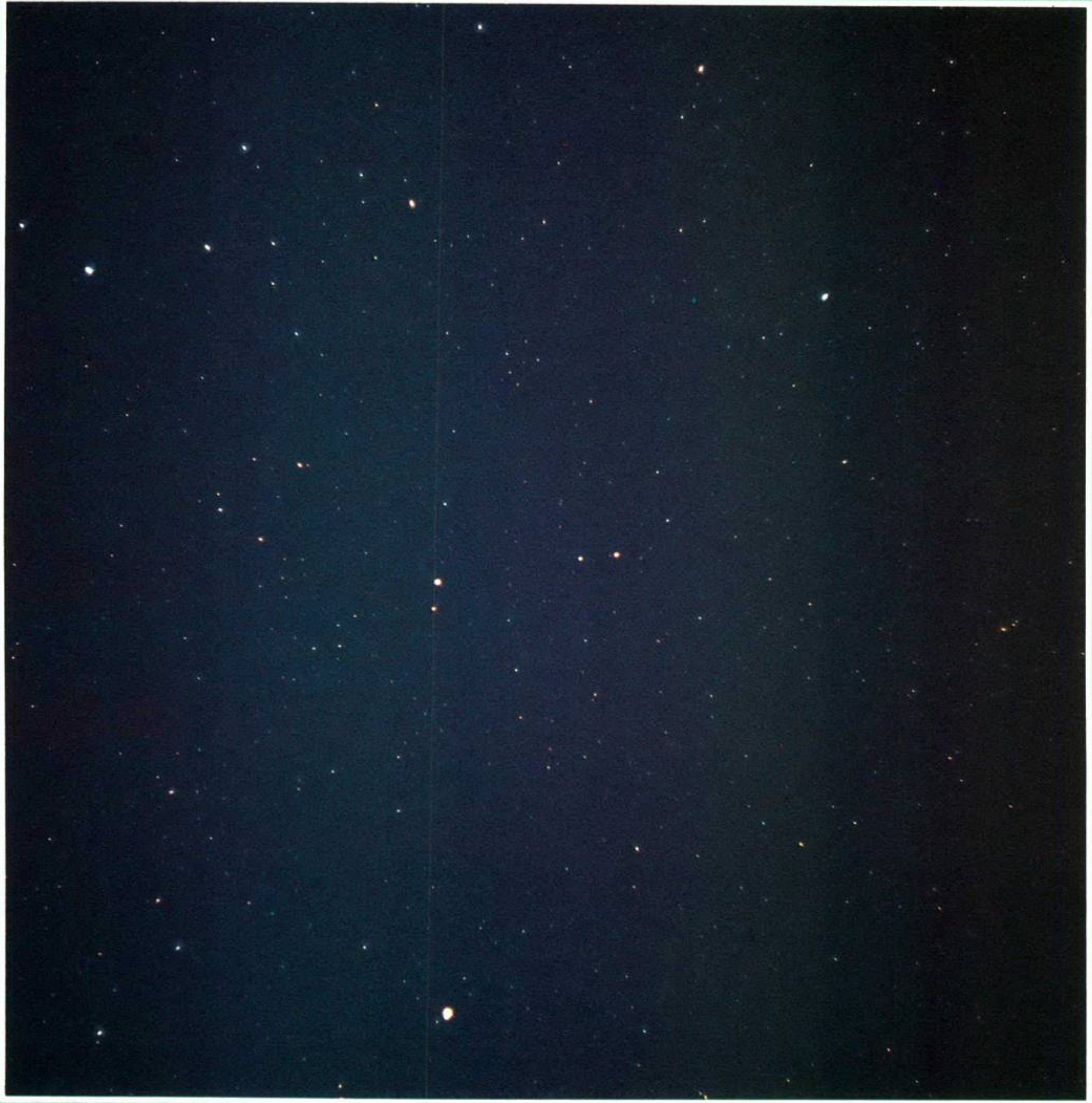
Merak
LYNX
CYGNUS
URSA MAJOR
M-44
DELPHINUS
Eltanin
Mizar
LEO MINOR
CANCER
LYRA
Vega
Milky Way
Altair
HERCULES
Cor Caroli
CANES VENATICI
E
W
AQUILA
M-13
Alphecca
BOOTES
Izar
COMA BERENICES
LEO
Rasalhague
CORONA BOREALIS
Arcturus
Regulus
SERPENS CAPUT
Denebola
SEXTANS
SERPENS CAUDA
OPHIUCHUS
Equator
VIRGO
Spica
SAGITTARIUS
Sabik
CRATER
CORVUS
Ecliptic
M-80
LIBRA
SCORPIUS
Antares
HYDRA
Menkent
LUPUS
CENTAURUS
S

This Star Dome rendering approximates the sky as it appears at about 10:30 p.m. Local Standard Time early in the month and one hour earlier toward the end of the month. The positions of planets can be found with the help of the Planet Finder on page 33.

The winter and summer solstices would have been extremely important at latitudes like that of Stonehenge — farther north than Egypt and the rest of the "fertile crescent" of the Near East, the so-called cradle of civilization — for the farther north you go, the greater is the difference in length of day between winter and summer. In the northernmost parts of Scotland, for example, June brings nights so short that evening twilight merges directly into morning twilight, and there is scarcely any night at all; while in December the situation is reversed, with an exceedingly long night and a very short day. Above the arctic circle, of course, summer brings the phenomenon of the "Midnight Sun" — days when the Sun never sets at all. We can easily imagine that those living in northerly climes would have a great deal of interest in the times of the winter and summer solstices.

But there seems to have been much more than this going on at Stonehenge. Once thought to be a temple of the Druids, Stonehenge is now known to be much more ancient than that religion, and its exact function is very much under debate among scholars. Whatever the final outcome of this debate, we are now sure that it was used for much more than just the observation of the sunrise on the summer solstice. Some have claimed it is actually a surprisingly efficient "computer" of sorts, designed to calculate the occurrence of lunar eclipses and other astronomical phenomena. While some have objected that the ancient people who built Stonehenge could not have had the scientific knowledge necessary for such a purpose, it now appears obvious that we have seriously underestimated the astronomical sophistication of primitive societies.



In recognition of this, a whole new field of archeological investigation has sprung up concerning the many stone circles of the British Isles and northern France of which Stonehenge is merely the best-known. This study of the astronomy of ancient, primitive cultures is called "archaeoastronomy," and it is now recognized that there is much we do not know about primitive man's astronomical knowledge. The modern findings of archaeoastronomy have begun to show that so-called "primitive" societies were capable of far more sophisticated astronomical observations than had been thought possible. The assertion that astronomy is the most ancient of the sciences and the mother of the rest seems to be more true than ever.

Close-Up

Bootes

This month's region might well be called the "Realm of the Doubles," for large numbers of double and multiple stars occupy this constellation which is otherwise poor in deep-sky objects. Webb long ago pointed out that "Bootes is rich in pairs, poor in clusters and nebulae" — a fact reflected in our table of selected objects. With the exception of a single globular cluster and a sprinkling of faint galaxies, the wonders here are all stellar — single, double, multiple, and variable — a somewhat surprising state of affairs since Bootes ranks 13th in size among all the constellations.

Arcturus

The visual magnet of this region is Arcturus, which at zero magnitude far outshines any other star in the area. Outranking both Vega and Capella, it is the brightest star north of the celestial equator and the 4th brightest over the entire sky. A K2-type giant sun, this lovely orange gem is one of our nearer stellar neighbors at just over 36 light-years away.

A fascinating account of this star was given by Webb: "A noble object at all times, but never so interesting as when, enveloped in the tail of Donati's Comet (1858) and only 20 minutes from the nucleus, it flashed out so vividly its superiority. Smyth calls it reddish

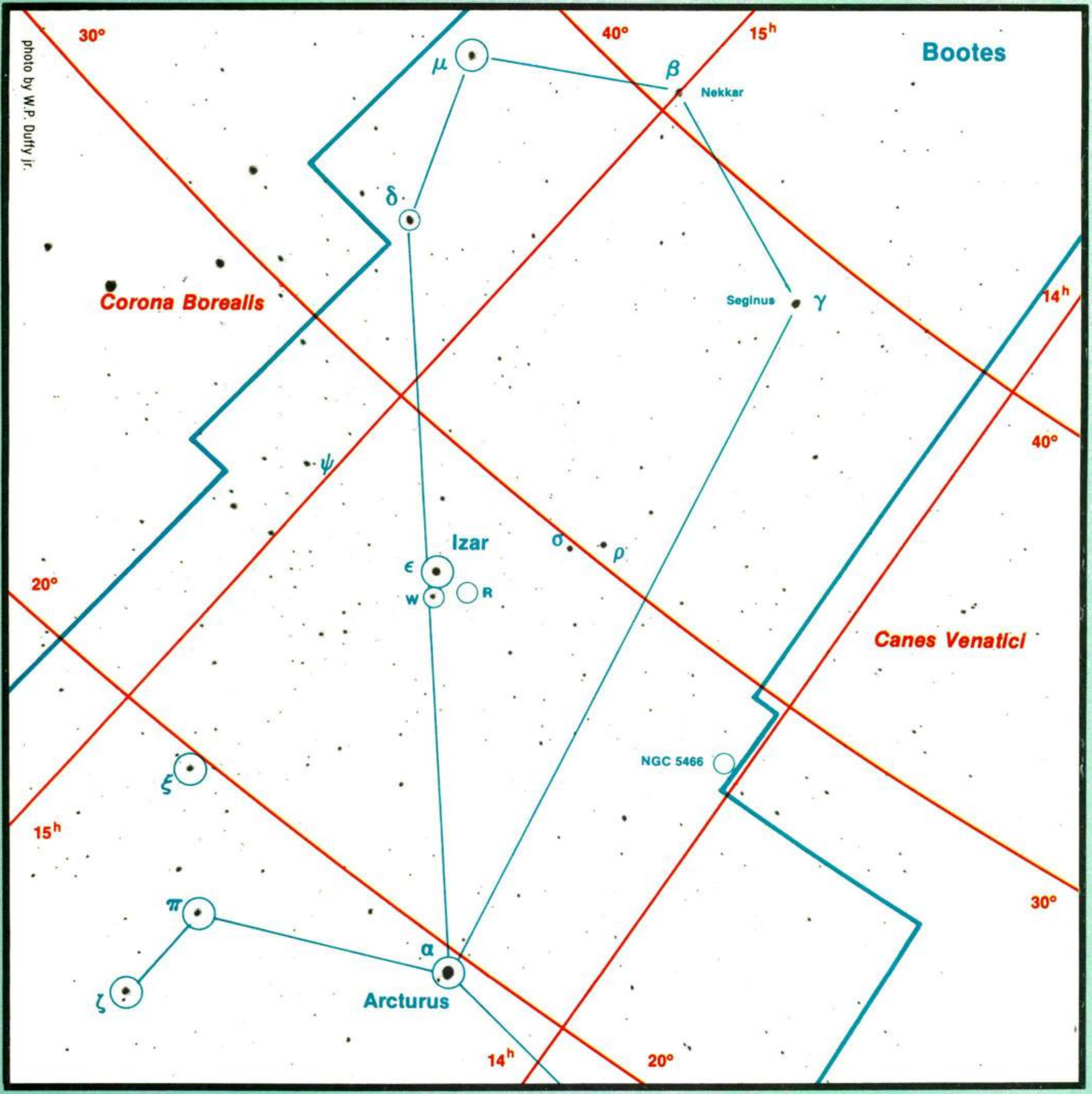


photo by W.P. Duffy jr.

yellow; it is golden yellow to me. Schmidt thought it had of late years lost all redness and was growing paler." Webb goes on to say that Schmidt had reported seeing Arcturus with the unaided eye 24 minutes before sunset (in the clear skies of Athens).

In general, the bright stars are neglected by amateurs as far as telescopic work is concerned. Few vary appreciably in brightness or have interesting companions, and yet these beacons possess a charm all their own — especially for those who enjoy observing star colors (an indication of stellar temperature).

The best way of seeing the tints of the bright stars is by means of their spurious diffraction disks (resulting from the wave nature of light), visible at high relative magnification. And it is here that the small telescope user has a definite advantage over large ones, for the apparent size of these disks increases as aperture decreases! The disks and attendant rings in a 2.4-inch (60 mm) refractor at 100 power or more are amazing to behold, but in a 6- or 8-inch at the same magnification are virtually invisible. Whatever size scope you have, for a real visual treat, try masking it down to an inch or two aperture using a cardboard stop (on-axis for a refractor, off-axis for a reflector or catadioptric to avoid their secondary obstruction).

An interesting and informative project would be the compilation of a list of bright star colors based on visual inspection of their diffraction disks. Although largely subjective in nature, such a roster would be internally consistent for any given observer using the same instrument for all the observations. The observed colors could then be compared to the actual spectral types given in catalogs for these stars. The use of well-corrected eyepieces (and barlow if used), and observation of the objects when on or near the meridian are two important factors in such an undertaking.

Xi (ξ) Bootis

If you're among those who believe that all double stars look alike, try this one. Our next offering is Xi (ξ) Bootis, a lovely yellow and ruddy-purple duo lying 9° due east of Arcturus that's a visual delight in even the smallest of telescopes.

Discovered by Sir William Herschel in 1780, Xi consists of 4.7 and 6.8 magnitude suns currently spaced 7 seconds apart near position angle 335°. This object is a well-known binary with an orbital period of 150 years; just past its widest separation of 7.2 seconds in 1977, it is now slowly closing up to a minimum near 2 seconds expected in the year 2065. Back in 1937, the two stars were just under 5 seconds apart in position angle 13°. There is also an unseen third body present circling one of the visible stars with a period of just over two years, the entire system lying only 22 light-years away.

As in the case of Epsilon (below), the tints here are lovely and marked. Webb gave them as yellow or clear yellow and reddish purple, and Smyth as deep yellow and flushed purple. Brown logged them as yellow and red, and Olcott as yellow and purple, adding "fine contrast." Other color impressions are to be found: both Dembowski and Meeus saw the components as yellow and orange, the latter observer stating that "this fine binary is now a very easy object in small telescopes." Interestingly, Muirden reported the tints here as yellow and *bluish*. The spectral types of the primary and companion are G8 and K4, respectively, agreeing well with the visual accounts.

Epsilon (ϵ) Bootis

Among the multitude of doubles in this month's region, the showpiece of them all is the star Epsilon (ϵ) Bootis located about 9° northeast of Arcturus. A stunning combination of a 2.5 magnitude yellow primary with a 5th magnitude blue-green companion 3 seconds of arc distant near position angle 340°, this duo is one of the most beautiful pairs in the entire heavens.

Epsilon is generally considered a test for 2 to 4-inch apertures, but a good 3-inch refractor readily splits the components at 75 to 100 power on a steady night. Less than average seeing, however, quickly makes this a difficult object to resolve in even an 8-inch scope. Calling this duo a "superb colored double," Robert Burnham, Jr. remarked: "One of the most beautiful of the double stars, though generally a difficult object for a 3-inch glass and not exactly easy for beginners even with a 6-inch."

So attractive is Epsilon in the telescope that the famed double star discoverer F.G.W. Struve christened it "Pulcherrima" — "most beautiful." Webb found it very yellow and very blue, and again light yellow and greenish, commenting "have seen it perfectly with a 2¼-inch achromat." Muirden also gave yellow and green, noting "fine contrast...needs high power." Pickering included it on his roster under finest colored double stars, calling it "A fine close pair" without mention of the tints themselves. Likewise, Chambers noted "colours fine" but did not give them.

Here again, the diffraction disks seen in a small telescope at high power are ideal for viewing the contrasting hues of bright pairs like Epsilon Bootis. Although large instruments more easily resolve tight doubles, their increased light grasp tends to overwhelm the eye, reducing its sensitivity to delicate celestial tints. Surely those who lament the fact they have only a small telescope would do well to consider that their humble instrument can provide views of these colored jewels of the sky unmatched by any telescope — no matter how large it may be.

Relatively fixed in both separation and position angle, sluggish Epsilon has not shown any definite orbital motion since its discovery nearly 150 years ago, but is undoubtedly a slow binary whose period must be well in excess of a thousand years. The spectral type of the primary is K1, that of the companion A2, and the duo lies about 220 light-years from us.

Zeta (ζ) Bootis

Color is not the sole attraction in double star observing — even white pairs are often striking, as our next object demonstrates. This is Zeta (ζ) Bootis, positioned 8° southeast of Arcturus and some 6° southwest of Xi (ξ). Another of Herschel's finds, it too is a binary system having a period of about 125 years.

Zeta is made up of a perfectly matched pair of 4.5 magnitude stars currently a tight 1.1 seconds apart in position angle 305°. It was last at its widest separation (1.2 seconds) in 1959 and will close up to only a few hundredths of a second around the year 2020, placing it beyond the resolving power of all optical telescopes. It will remain very nearly at its present separation and position angle over the coming decade.

Both Zeta's components are A2-type suns and nearly all observers find them white or off-white in hue. Smyth dubbed them "bright white, bluish white." Webb recorded them as both white and on another occasion as both pale yellow, remarking: "Excellent test: elongated or in contact as seen with 3.7-inch (refractor) at 144x and 250x, 1854; wide as seen with 9.3-inch reflector at 450x, 1869." The former observation was made 125 years ago when the stars were at their present separation, and the latter one 15 years later when the gap between them had dropped to under 0.9 second. At the time they were widest, Muirden considered them still "too close for 3-inch." How much magnification do you find necessary to split this silvery duo in your telescope on a good night at its present separation?

Selected Objects — Bootes

Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.
NGC-5466	●	8.5	5′	$14^h 03^m$	+28°46′
Kappa (κ)	★^{2}	4.6,6.6	13″	$14^h 12^m$	+52°01′
*Arcturus	★+	-0.1	--	$14^h 13^m$	+19°27′
Iota (ι)	★^{2}	4.8,8.3	38″	$14^h 14^m$	+51°36′
Struve 1835	★^{2}	5.1,6.6	6″	$14^h 21^m$	+08°40′
†R	m★	6.7-12.8	223^d	$14^h 35^m$	+26°57′
*Pi (π)	★^{2}	4.9,5.8	6″	$14^h 38^m$	+16°38′
*Zeta (ζ)	★^{2}	4.5,4.5	1″	$14^h 39^m$	+13°57′
W	∩★	5.0-5.5	--	$14^h 41^m$	+26°44′
*Epsilon (ϵ)	★^{2}	2.5,5.0	3″	$14^h 43^m$	+27°17′
39	★^{2}	6.1,6.6	3″	$14^h 48^m$	+48°56′
*Xi (ξ)	★^{2}	4.7,6.8	7″	$14^h 49^m$	+19°18′
*44	★^{2}	5.5,6.5-7.1	0.8″/6.5^h	$15^h 02^m$	+47°51′
Delta (δ)	★^{2}	3.5,7.8	105″	$15^h 13^m$	+33°30′
*Mu (μ)	★^{3}	4.5,7.2,7.8	109″,2″	$15^h 23^m$	+37°33′

*Detailed in Close-Up
†At maximum July 16th

★ Star
★+ Bright Star
★^{2} Double Star
★^{3} Triple Star
m★ Regular Variable
∩★ Irregular Variable
H★ Eclipsing Variable
○ Open Cluster
● Globular Cluster
■ Planetary Nebula
□ Bright Diffuse Nebula
§0 Elliptical Galaxy
§S Spiral Galaxy
§/ Barred Spiral Galaxy
§# Peculiar/Irregular Galaxy

Pi (π) Bootis

Should you be disappointed by Zeta, our next pair will more than compensate and refire your enthusiasm. This is Pi (π) Bootis, lying 7° southeast of Arcturus and forming a squat triangle with Zeta and Xi. Its 4.9 and 5.8 magnitude suns are currently just under 6 seconds apart in position angle 110°, and are neatly resolved in a 3-inch refractor at 45 power.

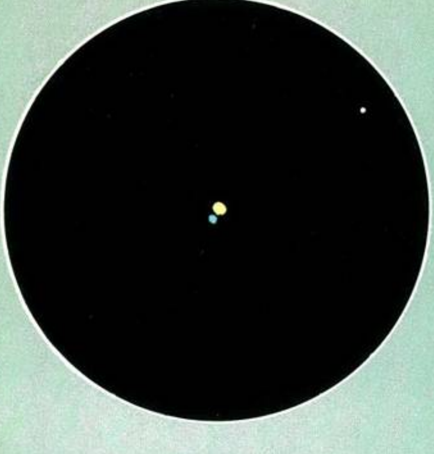
Pi's B9 primary and A5 companion both look white or bluish white to many observers. The pair appears on Colas' list from the 1890s of the finest white double stars. Olcott found the stars both white and Muirden tersely described them as a "white pair." Smyth noted the tints here as "white and creamy" while Webb called them "very white and a little tawny or ruddy." How do you find them?

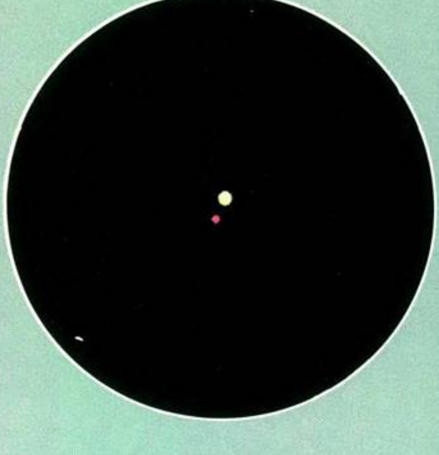
44 Bootis

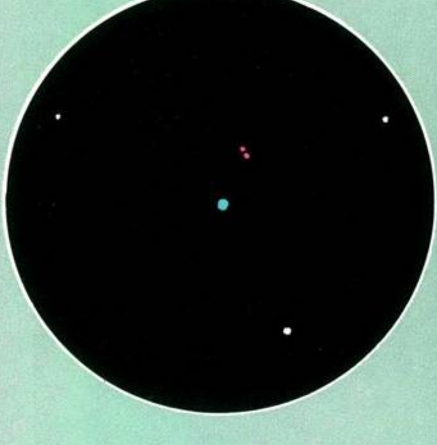
Just half a degree southwest of Kappa lies the fascinating variable-double star 44 (also known as i) Bootis. Its 5.5 magnitude primary has a very close companion a magnitude fainter in orbit about it, presently just 0.8 second distant near position angle 25 degrees. Both members of this visual pair are early G-type stars similar to our own Sun, and form a binary with a period of about 250 years. Minimum separation between the two of 0.5 second occurred last in 1970, when a 12-inch telescope was needed to split them. The pair is now slowly opening to an expected maximum of nearly 3 seconds about the year 2020.

The companion of 44 Bootis is itself a variable star — a W Ursae Majoris-type eclipsing system whose light drops about ½ magnitude (6.5 to 7.1) every 6½ hours. Even if your scope cannot resolve the visual pair, the change in the combined light of the entire system can be detected by careful comparison with surrounding non-variable stars. This fascinating triple is just over 40 light-years distant from us.

Perhaps of more direct interest at the eyepiece are the colors displayed by the visual components of the 44 Bootis system. This pair appears on Colas' list of the best white doubles, but Webb pointed out that there are "great differences as to colours" here. He logged them as yellow and bluish at one time, and as yellow and ruddy or purple another. Smyth found the stars pale white and lucid grey on one occasion and yellow and cerulean blue on another. Struve gave pale white and pale blue, while other observers have reported white and yellow, and yellow and orange. What heavenly hues do you see here?







Above: The bright close double Epsilon Bootis is a beautiful test double for a small telescope. Above right: The double (actually triple) system Xi Bootis is currently just past its widest separation. The color contrast is especially pleasing. Right: The fine triple star Mu Bootis has often been seen only as a wide double. Care must be exercised to separate the closer pair of nearly identical suns. Drawings by James Mullaney.

Mu (μ) Bootis

We conclude our survey of the wonders of the Bootes region with one of the finest triple stars in the summer sky. This is Mu (μ) Bootis, easily found forming an equilateral triangle with Beta and Delta (δ), lying to the east of them. Look for a close "double star" in the finder at its location.

Here we find a 4.5 magnitude primary star, 109 seconds from which (in position angle 170°) lies a close pair of fainter suns, magnitudes 7.2 and 7.8, 2 seconds apart in position angle 20°. This small duo is a visual binary with a period of 260 years; back in 1938, the components were separated by 1.8 seconds at a position angle of 36°. All three stars share a common proper motion together through space and are, therefore, physically related as "all one vast system" in Webb's words. Their distance from us is about 95 light-years or nearly 500 trillion miles.

Brown called Mu Bootis an "easy double" and pointed out that the dimmer star was itself a close binary that "needs at least 100 power for a notched split." Actually, a 4-inch scope at 100 diameters will give definite resolution in good seeing — a 2.4-inch refractor at these same powers shows the close pair as a notched egg.

Some observers mention only the wide double in their accounts, apparently unaware that three stars are present here (Olcott, for example). Smyth gave the colors of the two obvious stars as yellowish and greenish white, but most viewers find the primary bluish white and the close duo as both ruddy, lilac, or orange in hue. The former is an A7 (some sources F0) star, while the latter are both solar-type suns.

Barns makes a celestial mistake in his description of Mu Bootis, which reads: "Double-Double: 4-6.5; separation 108.5 seconds, and visual binary: 7.2-7.8. One of the pre-eminent quadruple systems." His "6.5" magnitude object represents the combined light of the close pair, so where is the fourth star in this supposed "quadruple" showpiece of the heavens?

Viewing double and multiple stars like those in Bootes with a small telescope is a delightful and relaxing way to spend a warm summer's evening under the sky. These colored jewels of the heavens — no two of which are exactly alike — are among the most easily found and observed of all deep-sky objects. Their exquisite and delicate beauty lies largely hidden to the eyes of man without optical aid, giving support to Emerson's contention that " Of all tools, the observatory is most sublime."

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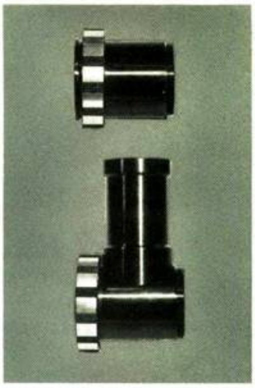

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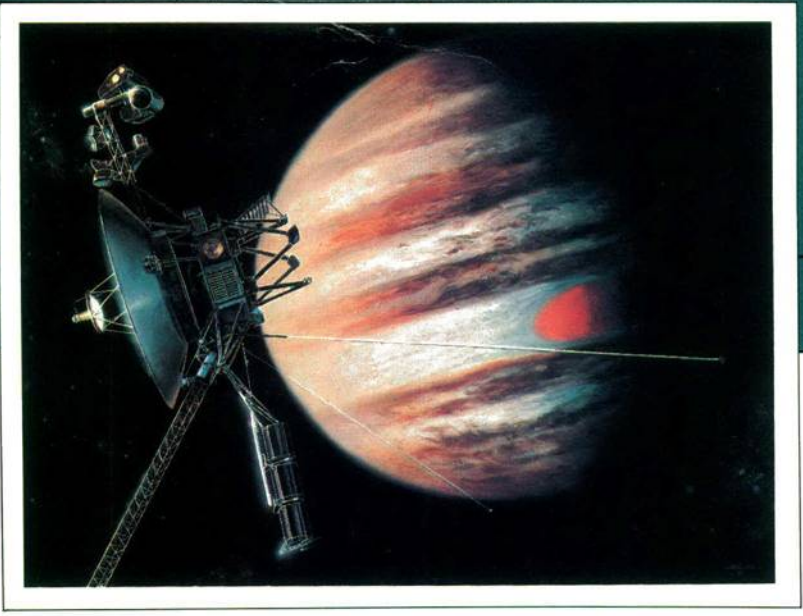

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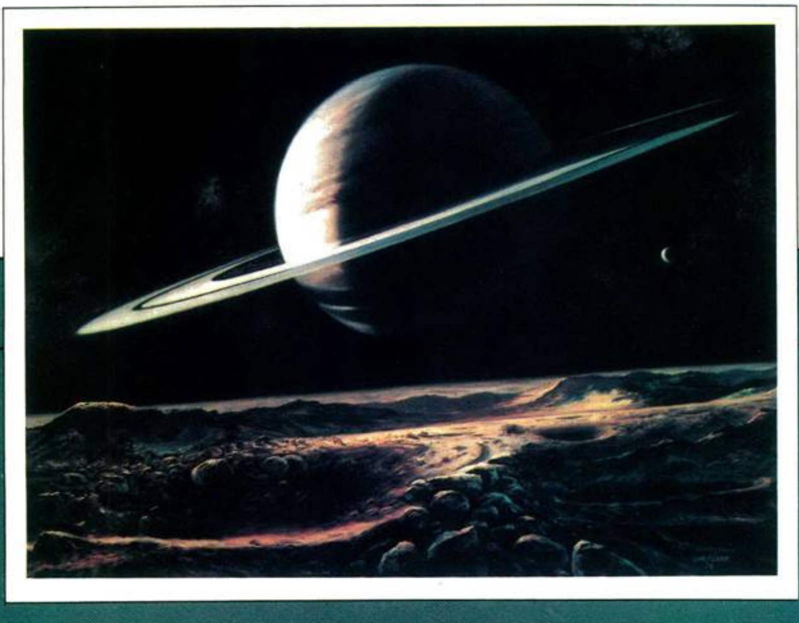

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